RICE

BY

EDWIN BINGHAM COPELAND

PROFESSOR OF PLANT PHYSIOLOGY
AND DEAN OF THE COLLEGE OF AGRICULTURE, RETIRED,
UNIVERSITY OF THE PHILIPPINES

MACMILLAN AND CO., LIMITED
ST. MARTIN'S STREET, LONDON
1924

PRINTED IN GREAT BRITAIN

CONTENTS

ILLUSTRATIONS

INTRODUCTION

RICE is believed to be the world's greatest crop. The International Institute of Agriculture estimates the normal annual production at four hundred and forty billion pounds of rough rice, which should produce well over three hundred billion pounds after removal of the hull, leaving it comparable with wheat, which is still estimated somewhat lower. No other human food is produced in quantities comparable to either of these. Rice is the surest and most regular of great crops. It is probably the staple food of the greatest number of people. And men live upon it more exclusively than upon any other food. The number of cultivated varieties probably exceeds that of all other grains combined.

Rice culture began in the unrecorded past. Botanical evidence for the belief that it began in south-eastern Asia will be presented later. Because the earliest history of rice is Chinese, some writers have maintained that its origin began in China. As there is no equally old Indian, Indo-Chinese, or Malayan history with which the Chinese may be compared, and as no history makes a valid pretence of reaching back nearly to the first cultivation of rice, this evidence is worthless. There is, however, negative historical evidence of value. Rice was not a crop of the Egyptians or Chaldeans in very ancient times. It is therefore improbable that its

culture originated in Africa and spread thence to Asia, a possibility which the botanical evidence would admit.

Linguistic evidence is older and more valuable than historic, for language is of course immeasurably older than its use in permanent records. This evidence is clear but not conclusive as to any definite locality. In classic Chinese, agriculture and rice culture are synonymous, showing that this was the staple crop while the language was taking form. Rice and food are synonymous in languages so numerous and widespread that we may feel positive that this was the principal food in the misty dawn of settled life, so long ago that human migrations which we only suspect have confused the question of its origin, beyond the possibility of solution. Since the botanical and linguistic evidence agrees to this extent, we may conclude that rice culture began in south-eastern Asia and may not locate it more definitely.

Its culture spread as far as Upper Asia prior to, at least, the later movements of the Aryan dispersal; for its name is alike in Zend and Sanskrit and similar in Old High Persian, and the migrants to the north-west would naturally have lost it. The Greeks learned of it and got its name from the Persians. Mediaeval Europe acquired it from the Saracens.

While no subject can be more important or interesting than mankind's chief food, rice has never before been the subject of book treatment in any Western language. The literature regarding it is extensive and exceedingly scattered. In its commercial aspects, business has demanded and obtained reliable information wherever it was obtainable. Much has been written in the Orient on the relation of rice to human ideas and ceremonies. There are numberless scattered statements and direc-

tions as to local cultivation. But there has been a remarkable absence of such knowledge of the particular physiology of the rice plant as must underlie any science of its culture; and what information of this kind does exist is isolated and largely undigested. Not all published information of this kind can have been located and used in preparing this book. One may, however, expect with full confidence that this collection and correlation of information will result promptly in the discovery and use of what may have been overlooked, that it will stimulate and facilitate the study of rice; and thereby, probably more than directly, help to make rice culture more effective. There is no other field in which well-expended effort will add as much to human food and health as it will if applied to the improvement of rice culture.

In the preparation of this book two basic principles have been observed:

First. The rice plant is a living thing. It responds as a living plant to whatever is done to it. The only possible sound understanding of what is, and what is not, good treatment depends upon knowledge of the response of the plant to the treatment it receives. This understanding becomes thorough, and can be used intelligently for the improvement of practice, and our judgement becomes secure instead of tentative in the measure of our ability to explain *why*, as well as *how*, each response is made. Accordingly, I have not been content with giving an account, brief and imperfect because of our present lack of knowledge, of the physiology of the rice plant, but have also tried wherever possible to explain the details of field practice by their physiological effects. Such explanations are far too uncommon in works on agriculture; but no argument is

needed to prove that practice based on understanding is safer than practice based on observation alone.

Second, but not less important. Rice-growing is business. The best method is that by which the operation is most profitable. It would never pay any grower to get the biggest crop that it is possible for his land to produce. Large crops and fine quality are certainly to be desired, but they are not the final objects of rice-growing, even at an experiment station. Attention is constantly given to quantity and quality because they are prime factors in determining profit. But there is always a point, which varies from place to place and changes with time, beyond which further effort to improve them will not pay. The fixing of this point must be left to the business judgement of the grower. The general principle, that all practice, and all advice, whatever its source, must be judged by business considerations alone, is urged upon every grower.

Although preferring the metric system, I have deferred to the probable convenience of the reader in the use of weights and measures. Such units as the *picul*, *cavan*, and *bouw*, already in use in very considerable literature, I have retained, with explanations, on the ground that statistics are of greatest use in the lands to which they apply. More local and less familiar units, such as the *công*, *jireb*, *feddân*, *mao*, and *hanegada*, have as a rule been translated to acres without comment; a surprising number of such terms are encountered in the study of rice. Where I have translated to the hundredweight, it is to a unit of one hundred avoirdupois pounds. I have likewise translated to tons of two thousand pounds; but in the use of original statistics, where comparison is not involved, I have left tons as found, metric, British, or short.

If the criticism of my work on the *Coco-nut*, that it gives undue attention to the Philippines, may be anticipated in the case of *Rice*, I would plead that it serves the reader's interest if the writer deals most thoroughly with the things he knows best. It is partly for this reason that California rice culture is given a place of prominence to which its industrial importance does not entitle it. Beside this, however, it properly represents the type of culture in which each day of labour produces the greatest amount of rice. As to the Philippines, the attention is not undue. The Philippine College of Agriculture has for some time been the seat of the most comprehensive, and on the whole the most effective, rice study in the world. Following the Japanese in the combined application of Oriental interest and scientific technique, the Filipinos are now working with the zeal of the morning. With Japan and the Philippines to choose between, as the Oriental lands, where there is reasonably complete publication on all phases of rice culture, and with a part of the Japanese publications beyond my reach, any other course than the use of the work of my own old students, for the general description of Oriental rice culture, would have been unnatural.

It is a pleasure to acknowledge the valuable help received in the course of this work. Mr. H. S. Silayan has assisted me in more ways than can be listed. Mr. A. C. Lipayon has likewise given helpful information and suggestions on many points. Chapter I. is largely the work of Mr. H. F. Copeland. Dr. C. V. Piper has helped us choose among the confusion of terms applied to the rice fruit. Dean C. F. Baker and Dr. R. B. Espino have placed in my hands a large number of unpublished papers on rice. Dr. N. B. Mendiola has let me use his valuable unpublished manuscript on Plant

Breeding in the Tropics. Dean Baker, Dr. L. B. Uichanco, and Professor E. O. Essig have given assistance in the treatment of insect pests. Mr. J. S. Camus has read and helpfully criticized the chapter on the Philippines. To Director E. D. Merrill of the Bureau of Science, and to Mr. Camus for the Bureau of Agriculture, I am indebted for the opportunity to use the photographs for which acknowledgement is also made as they appear. To the Secretary of the Department of Agriculture, Industry, and Commerce of the Netherlands-Indies, the Director of the Estación Arrocera de Sueca, Spain, and the Consul-General of the United States at Rio de Janeiro I am indebted for information otherwise inaccessible dealing with their respective countries. To all of these I tender thanks most gratefully.

CHAPTER I

THE BOTANY OF RICE

RICE is the name of a plant and of its produce. In the latter sense the word is correctly but indefinitely used to name the produce in every stage, but is more strictly applied to the milled grain as an article of commerce and to the cooked product. We will have little to do with cooked rice in this work, and no confusion will result from the use of one word to name the plant and its milled product. The languages of the Orient are rich in terms applying specifically to rice which has had particular treatment. One of these, paddy in its English form, means rice in the hull, which has also the trade name of rough rice. Paddy is also used in English as the name of a field of irrigated rice enclosed by a dike.

The rice plant, *Oryza sativa*, L., is a member of the great and important grass family. The genus *Oryza* is characterized by having perfect flowers, with six stamens, enclosed singly by two well-developed glumes, of which the inner is called the palet and the outer the lemma. At the base of each of these inner glumes is an empty outer glume, usually small and inconspicuous; these are known simply as glumes. Below the outer glumes the stem or pedicel is enlarged and imperfectly jointed. All that is above the joint constitutes a spikelet, which, as the crop matures, becomes one grain. The spikelets are laterally flattened, so that the least diameter of the grain is its thickness, and the intermediate diameter, length being the greatest, should be

distinguished as depth; unfortunately, these distinctions are not carefully observed. The spikelets of rice are borne in a loose panicle.

In many places where rice has been cultivated long and on a great scale, wild varieties of *Oryza sativa* are found. These may be native wild plants, or may be descended from cultivated rice. As long as they are not too different to be regarded as varieties, one may not be positive as to their origin. Besides *O. sativa* there are other species of the genus, wild grasses, found in tropical Africa and in south-eastern Asia and the neighbouring islands. As many of what are regarded as varieties have been named as species by some botanists, the number to be regarded as species is obviously a matter of judgement. It may be taken as the consensus of opinion of botanists that there are fully a dozen, but probably not two dozen, known. Of varieties of *O. sativa,* thousands are distinguishable, mostly cultivated forms, without names except in the vernacular of the places where they are found. There are also a considerable number of uncultivated varieties, some of which are troublesome weeds of rice fields.

Among the reports of a considerable number of species of *Oryza* indigenous in equatorial Africa, those dealing with *O. longistaminata,* Chev. et Roehr., are most interesting. This is a perennial, spreading by means of rhizomes, or underground runners. Analyses show no marked peculiarity of the grain, but the natives trade one measure of it for three of imported rice. It grows on rather light soil, and can evidently endure considerable salt. Attempts to introduce it to Queensland as a crop have shown that it produced too little grain there to be worth growing for human food, but that it did produce good forage and good hay.

Rice and the other species of *Oryza* must have common ancestors, and must have originated where those ancestors lived. We may therefore be sure that before rice was cultivated it was a native plant in the same general region where the other species are found. It is

unlikely that it was first cultivated in the Malay archipelago, because human culture as a whole went from the continent to the islands, not from the islands to the continent. Reason has already been given for doubting that its culture was introduced from Africa to Asia. The best supposition, therefore, is that rice is a native of south-eastern Asia.

The plant called wild rice in the northern United States and Canada belongs to a related genus, and is therefore not a real rice. There is also a wild grass in Brazil called *arroz brabo*, which, whatever it is, cannot well be rice.

Before the subject of rice varieties is left for the present, it should be stated that the great majority of them have never been described sufficiently well to make it known at all completely what their characteristics are. However, two facts should be kept in mind: when differences between kinds of rice are mentioned, or even ranges of size or behaviour, we are usually dealing with distinctive varietal characters. And whenever our information concerning any point is based upon study of a single variety or of a few varieties, it must not be assumed too confidently to be applicable to all.

The most convenient order of description of the structures and physiology of rice will be: *First.* A description of the grain, its germination, and the growth and vegetative structure of the plant. *Second.* A discussion of the nutrition of the plant, with especial attention to water and the mineral food. *Third.* The reproductive processes.

The Grain.—The grain of rice, inaccurately called a seed, although it is the thing planted, consists of the true fruit or kernel and the four glumes already mentioned and the very short stem to which they are attached. In most varieties it is elliptical in its broadest outline, and slightly oblique. Leaving a fuller statement of varietal peculiarities for Chapter IV., it may be said here there are varieties with almost spherical grains,

and others which have them very slender and curved. The colour of the grain of commercial varieties does not vary far from straw colour, and this is true too of the majority of all varieties; but there are still a large number of red ones, and others with every shade from brown and purple to black, and with striped and otherwise variegated hulls. The single grain of commercial rices weighs one-fiftieth of a gram, more or less, and is seven to ten millimetres long; there are varieties varying widely in these respects also.

The Hull.—The palet or palea, lemma, outer glumes, and the stem-tip to which they are attached, constitute the hull. The outer glumes are usually scale-like, two or three millimetres long and about one millimetre wide; but in a few varieties they are much larger, rarely even exceeding the inner glumes in length. They are usually appressed to the inner glumes, and quite inconspicuous. The lemma and palea are boat-shaped. The palea is just enough the smaller so that its edge fits inside that of the lemma, the two thus forming a thin case like a pill-box. The lemma bears five ridges—one along the keel, one about midway on each side, and one along each edge. The palea has three ridges, one along its keel and one along each edge, the latter two fitting inside those at the edges of the lemma, so that the hull closes tightly. The ridges of the lemma, and that along the keel of the palea, are clothed with more or less fine hairs, especially toward the tip; and less plentiful hairs may be found between the ridges. The whole surface of the hull feels rough. The degree of hairiness and roughness are varietal characters.

In the majority of rice varieties the tip of the lemma bears a stiff, rough awn on all or a part of the grains of the panicle. In some varieties only the grains at the tips of the main branches of the panicle bear awns, and these are short; in others, all grains are awned, and the awn may be several times as long as the rest of the grain. Awns protect the grain against various animal enemies, and are commonest on robust

varieties and on rice growing in deep water; but they make rice harder to handle after the harvest and are not characteristic of fine rice. The varieties cultivated in Europe and the United States, therefore, as a rule, have short awns or none, and this tends to be the case with pedigreed rices in the Orient.

In the good short-grained varieties less than 20 per cent of the weight of the grain is hull, and there are said to be varieties in which it is less than 10 per cent. In long-grained rices the proportion of hull is greater.

The Kernel.—The kernel or fruit is enclosed by the hull, and lies loose inside it when ripe. Botanically, the fruit of grasses is a caryopsis, a fruit of which the very thin fruit-coat is completely attached to the coats of the single seed. When the kernel is milled, the fruit-coat of course comes off first, and is therefore a part of the bran; while the seed-coats, lying inside it, are removed next, and are more likely to be a part of the polish. The kernel bears a scar at the tip, where the stigmas stood, and one at the base, where it was attached to its stem. Corresponding to the larger size of the lemma than that of the palea, the tip of the kernel is somewhat oblique. And there are ridges on the kernel corresponding to those of the hull, having been formed as a result of the pressure of the growing kernel against its case. The less prominent these ridges are—respectively, the shallower are the grooves between them—the better the milling qualities of the rice; because less of the kernel has then to be removed to make it smooth and white.

The seed itself consists of two thin coats, the endosperm and the embryo. When rice is polished in milling nothing is left except the endosperm, and some of this must always be removed to get rid of all of the tightly-adhering coats. There are very few varieties with coloured endosperm; but even those classed as white have more or less brownish matter in the coats. They have therefore to be removed completely to produce an attractive milled article. In coloured rice the colour

may be in all of the coats, or only in the outer one or two; and the coats may even be differently coloured.

The larger part of the bulk and weight of the kernel, as well as also of the entire grain, is made up of the endosperm. This is the structure in which the parent plant stores up food to support the growth of the prospective seedling, for the sake of which store of food alone we value rice. Making up so large a part of the kernel, it necessarily has the general shape of the latter, including the ridges; but these are smoothed off in milling. Its texture varies with the nature of the food stored. In common rice the larger part of it is vitreous, composed very largely of starch, but containing also an appreciable amount of albuminoid substance. The more completely vitreous, the harder, as a rule, is the kernel and the better the quality, as this is usually judged. A part of the endosperm, a very small part in the best commercial rices, is white, opaque, and chalky in texture. This may be in the centre, or against the *back* edge of the kernel, although it is called a "white belly." This part of the endosperm is relatively weak in albuminoids. The chalky portion may be reduced to the point where there is said to be none; it is likely to be smaller or absent in slender than in plump kernels. For reasons not well understood, wholly chalky kernels sometimes occur in crops of otherwise fine rice.

What is called glutinous rice has uniformly chalky and not very hard kernels. Kikkawa[1] says that "according to Shimoyama the endosperm contains only a small percentage of common starch, but it contains a considerable percentage of soluble starch and dextrine, besides some maltose." Such rice is sometimes called dextrinous, in distinction to starchy. It turns brown instead of blue when treated with iodine. It is called glutinous because it forms a sticky mass when cooked; but no substance which ought to be called gluten is responsible for this behaviour.

[1] Kikkawa, S., "On the Classification of Cultivated Rices," *Journ. Coll. Agric. Tokyo*, 3. (1912), 11-108.

The embryo occupies a small cavity sunk in the basal end of the endosperm on the side or edge toward the lemma. The greater part of its bulk is made up of a cotyledon (scutellum), which lies against the endosperm, lining the cavity. In germination it serves as a sucking-organ, drawing the food from the endosperm for the use of the growing seedling. The rest of the embryo is made up of the rudimentary root and shoot. These are attached to the cotyledon on the outer side, against the coats, which are thicker here than elsewhere.

Germination.—The requirements for germination are sufficient water and a proper temperature. Given these conditions, the embryo absorbs water and swells. The swelling cracks the lemma along the ridge at the keel, and the root and shoot grow out through the crack.

According to Akemine,[1] the minimum temperature for germination is 10° to 13° C., the optimum, 30° to 35°, and the maximum, 40°. H. S. Silayan, working at Stanford University in 1922, got similar results as to minimum and optimum, not testing the maximum. His material was seed of *wataribune*, *caloro*, *Colusa*, and *French*, the first two of Japanese and the last two of Italian origin. G. Ocfemia and H. F. Copeland, at the University of Wisconsin, at the same time, using seed from Louisiana and the Philippines, found germination impossible at temperatures nearly as low as 12°, and that it was incomplete even at 20°. Dr. F. T. McLean, working in the Philippines, found no germination at 15°, and that if growth had been started at a higher temperature it would stop completely at that temperature ; and that 20° was not far above the minimum. The obvious conclusion is that the varieties grown near the northern limit of rice culture are such as can germinate at materially lower temperatures than can the characteristically tropical varieties.

Akemine found that before germination is evident the grains must absorb water to the extent of about

[1] Akemine, M., in *Landw. Zeitschr.*, 63. (1914), 78. Review in *Internat. Rev.* (1914), 489.

25 per cent of their air-dry weight; the moisture in air-dry rice is usually 12 to 14 per cent. Submerging his seed to depths of 3 to 20 cm., Akemine found no effect of the depth of water upon germination; Silayan's results are identical in this respect. But both found better germination on moist soil than under water. Seed-beds, according to Akemine, should contain 60 to 90 per cent, by weight, of their water-holding capacity.

Light is without influence upon germination. Dr. Overton at Wisconsin and Dr. Peirce at Stanford have shown that rice will germinate without free oxygen, without which seed of most kinds will decompose in water. It is significant in this connection that in Akemine's experiments, soaking in water at 10°-15° for twenty days resulted in a loss of weight by whole grains of only 1·5 per cent; and that Peirce found that the heat liberated by germinating seed is much less in rice than in seed of other kinds. The foregoing observations all agree in indicating that the germination of rice is exceptionally economical. Rice has no dormant period; that is, it can germinate at any time after it is perfectly ripe. Stored under favourable conditions, it loses its vitality slowly; in some of his tests, Silayan secured 100 per cent germination, in fresh seed and in seed a year old. Tests in the Philippines showed a loss of vitality of about 15 per cent in a year, but in California we count on a loss of less than 10 per cent.

Under the most favourable conditions the germination of rice becomes externally evident after about two days. At temperatures approaching the minimum, the process is of course much slower; thus, in California it is usually five to seven days after the application of water before the sprouting of the grain is apparent. Conditions which delay the germination of the most vigorous seed delay that of weaker seed much more considerably, so that the sprouting of the different grains in a sample may be distributed over several weeks if the temperature is artificially kept near the minimum; and under such conditions the weaker grains, able to germinate under

favourable conditions, finally die instead of sprouting at all. That is, in judging the quality of seed, account should be taken of vigour as well as of the capacity to produce seedlings under ideal conditions. This is probably the basis of the most of the value of the mechanical selection of the heavier seed for the production of a good stand; but there have not been experiments careful enough to justify a final judgement on this point. Although most grains of good seed will germinate without free oxygen, submersion is a somewhat unfavourable condition. Where the first water is to be held on the field, the selection of seed by specific gravity, as by the use of brine, may therefore be particularly expedient.

When the seed is submerged in water, the first part of the embryo to appear is the epicotyl, which grows into the shoot, which grows rapidly until it reaches the air, while the root system develops but slowly. When seed germinates on moist soil, on the other hand, the first root appears before the shoot; it grows more rapidly than when the plant is submerged, while the shoot grows more slowly.

The Shoot.—The shoot comprises stem, leaves, and inflorescence, the part of the plant not normally in the ground. Except in giant varieties, the stem is concealed during most of its life by the leaf-sheaths, and at the base both are concealed by a mass of roots. The leaves are borne singly at definite points called nodes, and the parts of the stem between the nodes are called internodes. Most of the internodes of rice are very short, but a few of the upper ones elongate. Each single stem of a grass is a culm; its internodes are typically hollow, but may be practically solid if very short.

The distinguishable parts of a typical rice leaf are the sheath, the blade, the ligule, and the auricles. The sheath is an elongated, ribbon-shaped leaf base, rolled into a cylinder which at first encloses all of the younger parts of the shoot or branch. The blade is also long and narrow, but lies flat. A narrow band of different structure marks the junction of sheath and blade, and may

be of different colour. The auricles are small projections borne on this band, one on each side. Typically, they are sickle-shaped, with the concave side clasped around the sheath of the leaf next younger than the one which bears them, and with a row of long, slender, tender teeth on the convex side. They are usually coloured like the band, and often about 3 mm. long, but vary greatly in size, form, and colour, even on a single plant, and may be altogether absent. The ligule is a small scale, which appears as a continuation of the sheath a short distance beyond the place where the blade is attached to it. In general outline it is an acute isosceles triangle, commonly more than 1 cm. in height, divided into two parts by a crack from apex to base. Its texture is that of thin paper, and it is usually white. It stands appressed to the sheath of the next younger leaf.

The following observations on structure and growth are based on field study of varieties *French* and *caloro*, by H. F. Copeland and A. C. Lipayon. The first leaf is a mere scale a few millimetres long, rolled into a cylinder. A second scale, like the first but considerably larger, presently grows out through the end of the first. The third leaf is the first to bear a blade, and this is a few centimetres long. The next half-dozen or so leaves bear blades successively larger. The internodes below their points of attachment remain very short, but each sheath is enough longer than the preceding to project above the top of it. It does not usually grow enough so to project, until the rolled-up tip of the next younger leaf has grown out beyond it. When the blade of about the tenth leaf has attained its full size, its sheath still continuing to grow, the internode below its base may be 2 or 3 mm. long; but this internode or the next one younger continues to grow, to a length of several centimetres. This and the succeeding internodes, which are due to grow long, do so after the leaves borne at their respective upper ends have practically ceased to do so. Four leaves, more or less, are thus carried up by long internodes. The effect of the described manner of

growth is that while each of the earlier leaves exceeds in length the next older one by only a little, and attains its ultimate height in about a week, the tip of each of these later leaves continues for two or three weeks to be carried higher above the ground. Their sheaths are commonly rather shorter than those of the lower leaves, and accordingly they do not successively differ in height much more than do the leaves below.

The utmost vegetative leaf on each culm is the boot-leaf. Its blade is usually shorter and broader than that of its predecessors. The top of the sheath is constricted, and bears a reduced ligule, and there is no younger leaf to grow out through it. Below the top the sheath is distended by the young, enclosed panicle. This speedily emerges and flowers, soon after which all growth ceases, some time before the fruit is mature.

A bud is borne, in the axil of each leaf. Potentially a branch may grow from each bud; but actually, except in quite deep water, only the buds at the base of the culm, where the internodes are very short, produce branches. All of the culms of a plant appear, therefore, to spring from a common point. Each branch appears above the top of the sheath of the leaf in the axil of which it is borne, a week or more after the leaf has ceased to grow. The first internode of a branch is always short, and the leaf borne at the top of it is without a blade, although the sheath may be several centimetres long. Beyond this, a branch has fewer leaves than the main stem; and, within limits, each branch has fewer than the next older one of the same plant, though none has fewer than five or six. Branches formed early have a stem-region of short internodes, the leaves of which differ from those on the main culm only in that each exceeds the next older one in height by a greater interval, so that the branch soon rivals the main stem with its leaves, in total height. The panicles appear, flower, and ripen the fruit at the same time on the main stem and the branches. Too deep water, too open a stand, too late a start, or too much nitrogen, may cause

the development of buds into branches to continue longer than it should, so that the later branches do not flower and fruit with the crop as a whole, or do not do so at all.

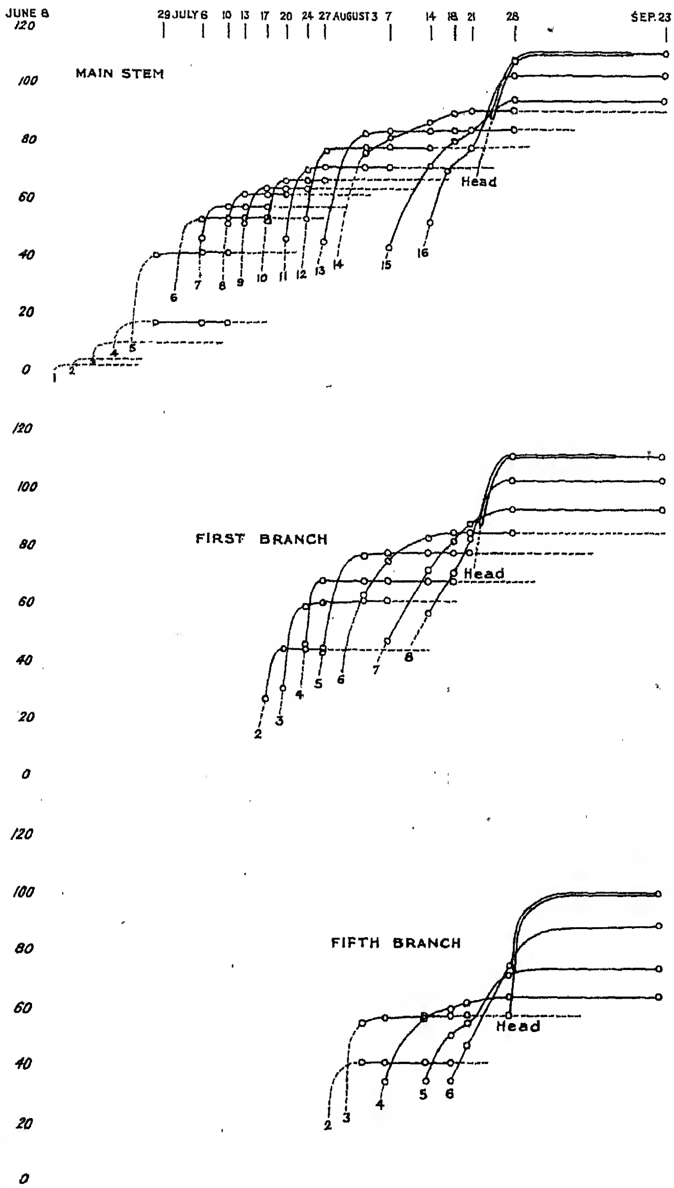
The total time between germination and maturity varies with the variety and with the conditions of growth. According to Camus,[1] the records of the Philippine Bureau of Agriculture, covering more than twelve hundred varieties, show extremes of 94 and 221 days. Vibar found the mean of a large number of Philippine varieties to lie between 161 and 180 days. Extremes reported elsewhere, ignoring perennial rice, are 10 months for the Cambodian floating rice, and 50 or 60 days in several parts of India.

The accompanying six graphs will make clear the distribution of the growth through the life period of the plant. These are three each of *French* and *caloro*, one representing the main culm, one an early branch, and one a late branch. Each line represents the height in centimetres, from ground to tip, of one leaf. The solid lines represent measurements made on the individual plant; the dotted lines are inserted on the authority of numerous measurements of other plants. The period from flowering to maturity is indicated by the double line in the curve of the head.

To say that a certain variety has leaves of a certain size means very little unless one is told what particular leaves are meant. This will be clear from the following table of measurements of leaves and internodes on one plant of *French* rice, made when the main panicle was in flower. Most, at least, of the other panicles were full grown, but several of the peduncles were still short; if the combined length of panicle and peduncle is less than that of the sheath of the boot-leaf, the panicle remains entirely enclosed. This table gives a very good quantitative idea of a rice plant.

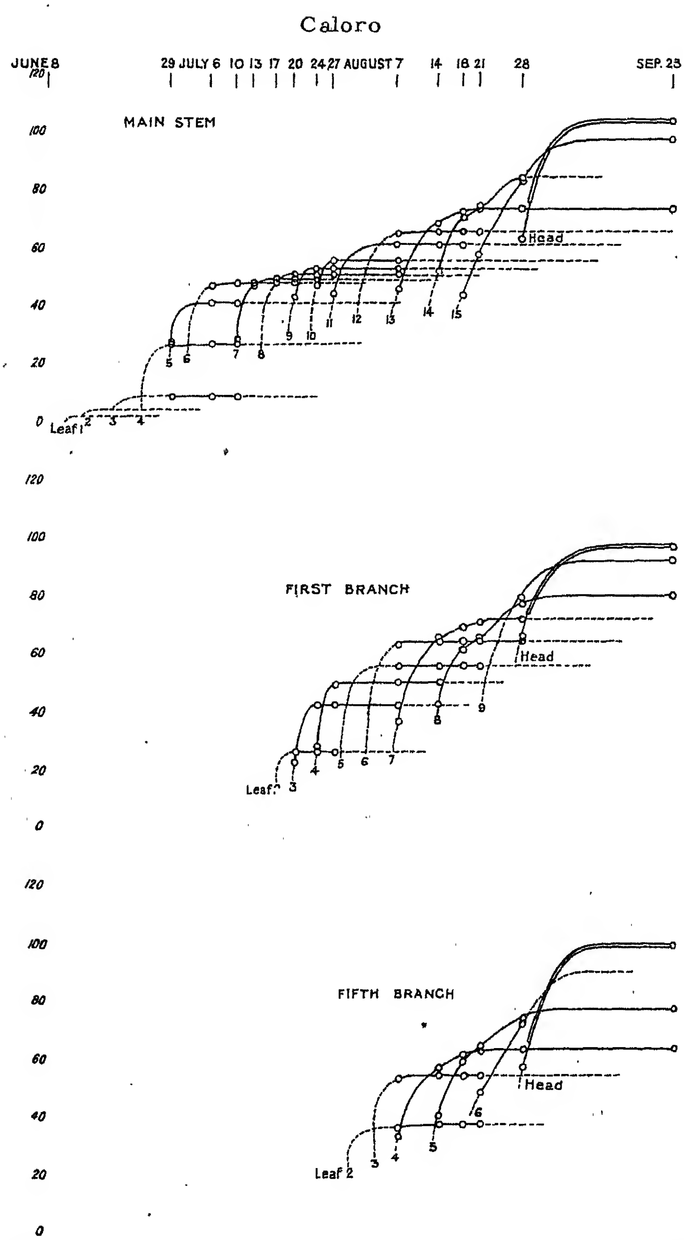
[1] Camus, J. S., "Rice in the Philippines," *Bureau of Agric. Bull.*, No. 37, 1921.

Française



To face p. 12

H. F. Copeland, del



To face p. 12

H. F. Copeland, *del.*

Leaf Number.	Length of Internode below the Leaf.	Length of Sheath.	Length of Blade.	Width of Blade.
MAIN STEM				
	cm.	cm.	cm.	cm.
8	..	23·2	36·7	0·4
9	..	22·0	39·1	0·6
10	..	23·0	41·3	0·7
11	1·8	23·6	46·1	0·9
12	8·1	23·1	51·6	1·0
13	20·1	23·6	41·6	1·1
14	23·8	29·6	24·5	1·3
Length of peduncle, 31·5 cm. ; length of panicle, 21·2 cm.				
FIRST BRANCH				
3	..	22·3	33·9	0·7
4	0·5	23·8	41·7	0·8
5	7·4	22·3	50·8	0·9
6	19·8	23·4	45·3	1·0
7	23·0	28·5	27·5	1·3
Length of peduncle, 32·1 ; length of panicle, 21·7.				
SECOND BRANCH				
4	..	23·2	38·3	0·7
5	4·5	22·8	49·2	0·9
6	18·5	23·6	48·1	1·1
7	26·2	28·4	30·6	1·3
Length of peduncle, 12·6 ; length of panicle, 21·7.				
THIRD BRANCH				
1	..	12·6	..	..
2	..	22·9	13·1	0·6
3	7·6	20·7	31·2	0·8
4	14·6	20·6	31·5	1·0
5	8·1	22·4	20·5	1·2
Length of peduncle, 4·1 ; length of panicle, 16·8.				
FOURTH BRANCH				
1	..	9·6	..	..
2	..	20·3	11·1	0·6
3	4·9	20·2	31·6	0·8
4	16·1	20·5	32·4	0·9
5	8·3	23·7	21·8	1·2
Length of peduncle, 3·6 ; length of panicle, 16·3.				
FIFTH BRANCH				
1	..	15·5	..	..
2	0·8	22·8	17·5	0·7
3	9·9	20·7	31·9	0·9
4	11·4	20·2	30·0	1·0
5	5·4	23·4	17·9	1·1
Length of peduncle, 1·8 ; length of panicle, 16·8.				
SIXTH BRANCH				
1	..	7·6	..	..
2	..	17·1	6·6	0·5
3	0·4	20·4	23·1	0·7
4	11·6	19·2	31·8	0·8
5	7·8	18·3	21·4	0·9
6	2·7	21·9	13·2	1·0
Length of peduncle, 1·2 ; length of panicle, 15·2.				

Where measurements of the blades are wanting, the blades had died and fallen off or were beyond measurement. Old leaves die continually as new ones are formed, so that the number of healthy leaves on a culm of *French* is usually four or five.

As the crop fills, and the plants come to bear a considerable weight at the top, winds may blow them over, or they may even fall down of themselves. The rice is then said to be lodged, and mechanical harvest is difficult or impossible. If lodging occurs before maturity the ripening will be imperfect and uneven. Short, robust plants do not lodge readily. The lodging-resistant qualities are varietal characteristics, but may be modified greatly by the conditions of growth. Continuous submergence predisposes to lodging, by interfering with the development of the mechanical tissues of the culm and stimulating its growth in length. Too much nitrogen works in the same way, by stimulating growth in height and of the leaves. According to Marcarelli,[1] cold weather at the time when stooling should be most active checks root development and results in lodging. Mendiola [2] says: "From the results of Peralta and Labrador, it may be deduced that length of culm and breaking strength of culm are positively correlated"; in other words, that tall plants have strong stems. However, the selection of tall plants would probably not result in freedom from lodging.

The Root.—Adventitious roots appear early in the life of the plant, and the primary root is soon indistinguishable. Many of the roots are evidently in rings, emerging below the nodes, but the nodes are so close together in the region where the roots are borne that the arrangement is not very clear. The roots grow through the sheaths of the dead leaves and extend out in all directions, but tend to run more horizontally than downward. As new roots form, the old ones develop an impervious

[1] Marcarelli, B., in *Giorn. di Risic.*, 8. (1918), 7. Review in *Internat. Rev.*, 9. (1918), 539.

[2] Mendiola, N. B., *Methods of Breeding Tropical Crops* (manuscript).

layer, first near the attachment to the stem, and finally extending along the whole root, which then dies. A little behind the tip, where the root is still white and tender, many fine white branches are found; these turn yellow and die, with the progressive encasement of the root which bears them. Of ten plants of *French*, all thirty-four days old and having one culm each, the average number of roots was 16, and the average length of the longest root was 15·6 cm. The number is lower than it might have been, because the plants were growing in water 20 cm. deep. As the plants grow older the number of roots, living and dead, increases rapidly, until about the time of elongation of the stem, after which very few new ones are formed. The dying of the old ones goes on, and, according to Herrero,[1] the dry weight of the root system actually decreases after the panicle appears.

The greatest number of roots found on any plant of *French* was 202; this plant was amply spaced and had ten culms. The least number on a plant about to flower was 42, on a crowded plant with a single culm. The longest root found measured 40·1 cm., and the least length of the longest root on a plant was 18·5 cm., the latter on a crowded plant with one culm. The length of the roots is correlated with the general vigour and size of the plant, and their number with the number of culms. The numerical relation follows from the fact that roots are formed on the branches as on the main stem; but the number is not proportional, because the branches have fewer nodes and their bases are so crowded together as to interfere with the formation of roots on all sides. It is impossible to determine a typical number of roots for a plant, because the condition of their most perfect development is uneconomical, involving too wide a spacing for the production of a maximum crop.

Nutrition.—The rate of growth of the plant and the amount of its crop depend directly upon its nutrition.

[1] Herrero, M., "Marche de l'absorption des principes fertilizants dans le riz," *Actes du Congrès Internat. de Riziculture*, Valencia, 1914, p. 128.

The most characteristic of the nutritive processes of plants is photosynthesis, in which starch or sugar is formed from carbon dioxide and water by the use of the energy of sunlight. The reverse process, common to plants and animals, by which carbon dioxide and water are set free again, is respiration. All that is specifically known about respiration in rice has already been stated in connection with germination. The only determinations of the rate of photosynthesis of rice were made by Dr. F. T. McLean, and are unpublished. They showed that rice performs this function a little less rapidly than sugar-cane in proportion to the area of leaf, but several times as rapidly as the coco-nut.

Since sunshine must furnish the energy for photosynthesis (as well as for another reason), rice wants all of the illumination that in nature it can get. Generally, cloudy weather is bad for it. Weeds which rival or exceed it in height are especially injurious. And in the shade of trees practically no crop is produced.

The carbon dioxide enters the leaf chiefly through pores, in both surfaces, called stomata. At the same time, vapour of water escapes through these pores, after evaporating from the cell-surfaces within the leaf. The cells in turn draw water from the system of vessels which is continuous from near the tips of the roots to and through the veins of the leaves. The roots get the water from the soil, and with it get, too, such substances as are dissolved in the soil water; and these substances go in general with the water to the leaves. But they are mostly substances which cannot evaporate; they are therefore left in the leaves when the water evaporates. The evaporation of water from the leaves is called transpiration. Transpiration is sometimes regarded as a necessary consequence of such a leaf structure as is necessary for rapid photosynthesis, and this aspect of it is important when plants suffer from containing too little water. But it has very great positive importance, as the process by which plants get the most of their mineral food.

Excepting carbon dioxide, plants get all of their food from the soil. It consists of water and of other substances dissolved in water. A little of these substances would diffuse into the roots without any movement of the water; but rice could not get enough of them to produce any crop without the very much larger amounts which it secures by absorbing and transpiring large quantities of the water in which they come dissolved. Active transpiration is therefore necessary for the sake of an adequate supply of food from the soil.

The rate of transpiration depends upon the openness of the stomata and the possible rate of evaporation of free water. The openness of the stomata depends upon the illumination and the amount of water in the plant; here is a second reason for the necessity of light. The rate of evaporation of free water depends upon the temperature and the dryness of the air. Direct sunlight makes the leaves materially warmer than the air about them, and so increases the transpiration; which is a third and very important reason why rice must be in a position to receive all the sunshine it can. The air over an irrigated rice field is naturally quite humid. Any movement of it by wind changes it and promotes transpiration, just as dryness does. Draining off the water during a part of the season of growth provides better conditions for transpiration, and may be of material benefit in this way.

The experiments of Peralta [1] in the Philippines showed great differences in the growth and production of rice planted in the different months of the year. These differences showed little relation to the several independent factors which determine the rate of evaporation, but followed closely the curve of the total evaporation during the growing season. It is not to be assumed that the several factors are without effect. Insolation, for example, affects photosynthesis as well

[1] Peralta, F. de, "A Study of the Relation of Climatic Conditions to the Vegetative Growth and Seed Production of Rice," *Phil. Agriculturist*, 7. (1919), 159.

as transpiration. And as all vital processes are chemical and physical in their nature, they must be affected by the temperature. The case is rather that, in the Philippines, and presumably in other tropical rice countries, transpiration is a function of such dominant importance that the collective effect of the factors controlling evaporation masks their individual effects upon the plant. Marcarelli, on the basis of study in Italy, states that heat is the most important environmental factor, and that clearness of sky is second in importance; this may well be true in Italy without being so in the tropics.

Because food from the soil is essential for the performance of all vital functions, including photosynthesis, and in very minor degree because of the weight of such food itself, there is a relation between the dry weight of a plant (its weight not including water) at any time and the amount of water it has transpired. The figure obtained by dividing the weight of transpired water by the dry weight is technically called the water requirement. This figure is different for different plants, presumably also for different varieties of rice, and varies with the conditions of growth. Leather (as reviewed by Briggs and Shantz), working at Pusa, India, found it to vary, in the case of rice, from 800 to 1106. The least water requirements were shown by plants growing in soil, to each 200,000 parts of which there had been added one part of calcium nitrate and substances yielding two parts of soluble phosphoric acid. The nitrate without the phosphate gave intermediate results. Briggs and Shantz,[1] in work in Colorado, where the rice did not mature, obtained average figures of 519 in 1912 and 744 in 1913. Espino,[2] in a Baltimore greenhouse with seedlings reaching an age of only three weeks, found a range from 808 to 1192. The preceding figures are not comparable. So far as can be judged from

[1] Briggs, L. J., and Shantz, H. L., "Relative Water Requirements of Plants," *Journ. Agric. Research*, 3. (1914), 1. A review of the literature by the same authors, U.S.D.A.Bu. of Plant Industry, *Bull.*, No. 285, 1913.

[2] Espino, R. B., "Some Aspects of the Salt Requirements of young Rice Plants," *Phil. Journ. Science*, 16. (1920), 455-523.

them, rice needs to transpire more than do the other grass grains, but not more than do various other plants. Very much more complete information, especially as to the relation between water requirement and the climatic and soil conditions, ought to be obtained, because of the intimate relation between this subject and the plant's use of fertilizers.

In the case of rice, the water requirement does not indicate the amount of water which must be supplied to the field. Varieties differ exceedingly, upland rice thriving in unsaturated soil, while most varieties require more or less submergence, and some thrive in water 6 to 15 feet deep. The following table of field counts by Silayan, of *caloro*, illustrates the response of ordinary lowland rice to varying depths of water in California.

Depth in inches	4	8 to 10	14	18	20 or more
Number of unit areas	2	6	7	5	2
Average plants per sq. yd.	53	51	27	12	12
Average culms per sq. yd.	101	228	163	129	115

It appears from these counts that with increasing depth the number of plants decreases, but that up to 18 inches the number of culms per plant increases. The latter results from the wider spacing of the plants. The former may be said to be due to drowning, but this is not a real explanation. As the plants which tiller with reasonable freedom continue to express their superior vigour by bearing larger panicles in general than do those with a single culm, the best crop of the plots represented in this table was produced where the water was 8 to 10 inches deep. This agrees with results obtained in 1923 at the Cortena rice field station of the University of California, likewise on old land. The average of many determinations, extending over eight years, at the U.S. rice station at Biggs[1] is very slightly higher where the water was 6 inches deep, and substantially the same at 8 and 4 inches. Climatic conditions, to be described later, demand deeper water in

[1] Jones, J. W., "Rice Experiments at the Biggs Rice Field Station in California," U.S.D.A. *Department Bull.*, No. 1155, 1923.

California than in most lands. Jack[1] states that in Malaya seedlings are placed especially close together in deep water, "because deep water inhibits tillering considerably and if very deep even kills young seedlings." The adjustment of the spacing, to secure the best crop, is of course easy and most expedient where rice is transplanted; and the regulation of depth is in general easiest where the paddies are small. Jack says that "A good variety such as *Seraup* may produce as many as 50 tillers per plant, but under ordinary good agricultural conditions 18-20 tillers per plant is a good average, while in poor soil 2-3 tillers per plant are frequently found." The varieties grown in California are certainly to be classed as free-tillering, but an average of more than 6 culms per plant can be obtained only by uneconomically wide spacing. The difference may be an effect of the transplanting.

Besides water, carbon dioxide, and free oxygen, the substances which a plant must have are compounds of at least seven chemical elements—nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron. The roots exercise little or no selection in absorbing substances dissolved in the water in the soil about them —they take what comes; but the ability of the plant to make use of the elements supplied to it depends upon their chemical combination, on their quantity, both absolute and relative to each other, and upon the stage in its life-history which the plant has reached. It can make good use of sulphur, phosphorus, potassium, calcium, magnesium, and iron in the form of the sulphates and phosphates of the metals named. Failure does not result from the application of these salts to rice as fertilizers, and there has been no great effort to find other useful forms.

Among the metals named, iron is a very weak base. When its salts are dissolved they tend to decompose, and in an alkaline solution do decompose, reacting with

[1] Jack, H. W., "Rice in Malaya," *Malayan Agric. Journ.*, 11. (1923), Nos. 5 and 6.

water to form ferrous and ferric hydroxide, both of which are unavailable to the plant. Calcium carbonate, in distinction to other salts of calcium, usually injures rice, which is believed to be because its presence, unless neutralized by acids, causes alkalinity and makes iron unavailable. The plant may then starve for want of iron, however much of it is present about its roots. The phosphate of iron, because it is almost insoluble and therefore does not decompose, has seemed to be the best form for use in experiments. According to Gile,[1] the chloride poisons the roots, though the tops—for a time at least—may show improved growth as a result of its application. Rice needs to absorb exceedingly little iron; water distilled through an iron tube, or running from an iron roof, contains enough of it.

In the forms of nitrogen which it requires, rice differs from most plants. It requires both nitrates and derivatives of ammonia. A large number of experimenters, whose work is reviewed by Espino, have shown that the application of nitrogen in the form of ammonium salts or amides improves growth and yield, while the application of nitrates is expedient only in the later stages of the life of the plant. Presumably, rice evolved this peculiarity in adaptation to life in marshes, where little free oxygen could reach the soil about its roots, and where, consequently, nitrates could be formed only very slowly by the decomposition of organic matter. Nagaoka [2] found that upland rice, which grows normally in aerated soil, shows less need of ammoniacal compounds than does lowland. Espino's own experiments, however, which were solution cultures, so that he knew what was available to the plant to an extent never possible with soil cultures, showed that even young rice does not prosper without any nitrate food at all. Plants growing in solutions containing ammonium salts but no nitrates grew as rapidly as did plants which could

[1] Gile, P. L., "Assimilation of Colloidal Iron by Rice," *Journ. Agric. Research*, 3. (1914), 205.

[2] Nagaoka, M., "On the Behaviour of Rice Plants to Nitrates and Ammonium," *Bull. Coll. Agric. Tokyo*, 6. (1904), 285.

get both, but the tips of their leaves always died. His experiments were not carried far enough to show whether or not ammonium salts are necessary throughout the life of the plant. Kelley,[1] working with pot cultures, found that the addition of nitrate to the soil was beneficial during the later part of the plant's life, beginning near the time of flowering. Various physiological explanations have been suggested for the ineffectiveness of nitrate fertilizers during the earlier stages. Nagaoka has suggested that the formation of nitrites under anaerobic conditions furnishes the explanation; he was able to detect nitrites in pot cultures heavily fertilized with nitrates, and nitrites are well known to be toxic. The facts that nitrates are characteristically very soluble and not very subject to adsorption by the soil, and are therefore easily leached away, may have something to do with the evolutionary explanation of their unimportance, but do not contribute to a physiological explanation.

With respect to the quantities in which rice requires the various elements, the first thing to be noted is that balance between them is sometimes more important than absolute quantity. In Espino's experiments, monopotassium phosphate, ammonium sulphate, calcium nitrate, and magnesium sulphate were found to provide a satisfactory combination of salts to provide the elements involved, and the best molecular proportion among those tested was found to be:

$$KH_2PO_4 : (NH_4)_2SO_4 : Ca(NO_3)_2 : MgSO_4 = 1 : 1{\cdot}5 : 1{\cdot}5 : 4.$$

Espino concludes: "It is safe to say that one very excellent solution would have the potassium, ammonium, and calcium salts in about the same proportions, while the molecular partial concentration of the magnesium salt should be four or five times as great as that of any one of the others. The tolerance of these plants for magnesium sulphate is especially remark-

[1] Kelley, W. P., "Assimilation of Nitrogen by Rice," Hawaii Agric. Exp. Stat., *Bull.*, No. 24, 1911.

able." An excess of magnesium is, however, possible. In Zamora's [1] experiments with pot cultures, no amount of magnesium as a fertilizer was beneficial, while the addition of lime, within limits, was so.

As might have been anticipated from its native habitat, rice is notable, among cultivated plants, for the lowness of the total concentration of nutrient salts which is most favourable to its growth. In Espino's experiments, the best of the total molecular concentrations used proved to be 0·0016 and 0·0038. Such solutions contain roughly 0·02 per cent to 0·04 per cent of solid matter; and Espino believes that a better concentration than either of these would lie between them and nearer to the lower. Wheat thrives best with solutions more or less ten times as concentrated.

The very great difference between rice and other grain reported by Espino may have been the result of his working only with plants in the first stages of growth. But it would be likely to follow from its having a higher water requirement that rice would demand weaker solutions than other grains. The same relation appears again in total amount of solid food removed from the soil by the various grains, rice being easy on the soil, as shown by the following table, which Miege [2] ascribes to Garola. The figures are kilograms per hectare taken from the soil by a normal crop, and for each 100 kg. of grain.

	For a Normal Crop.				Per 100 kg. of Grain.	
	Nitrogen.	Phosphoric Acid.	Lime.	Potash.	Nitrogen.	Lime.
Spring wheat	138	74	62	190	4·31	1·94
Spring barley	86	79	42	93	3·93	1·93
Oats	126	78	38	129	5·06	1·52
Maize	65	29	28	82	2·27	0·95
Millet	65	56	31	112	2·62	1·25
Rice	97	26	27	62	2·41	0·70

[1] Zamora, J., "Fertilizers and the Growth of Rice," *Phil. Agric. and Forester*, 1. (1911), 152.

[2] Miège, E., "Mémoire sur les procédés . . . de fumure du riz, et spécialement sur. . . . la cyanamide," *Congrès Internat. de Riziculture*, Valencia, 1914, p. 166.

What a plant has taken from the soil is determined by chemical analysis of the plant. A considerable number of such analyses have been made, because they are supposed to indicate the substances which should be applied as fertilizers. They are not safely comparable, because the results depend upon many outside local conditions as well as upon the variety of rice. Thus it is Spanish practice to fertilize *amonquili* 75 per cent more heavily than *bomba*; and wherever the subject has been studied, varieties have been found to be unlike in their reaction to differences in the soil or in fertilizers. Merely to give a general idea, the following computations, published by Camus in the Philippines, and made by Kellner in Japan and McDonnell in South Carolina, are tabulated.

Author.	Area.	Weight		Weight		
		Of Grain.	Of Straw.	Of Nitrogen.	Of P_2O_5.	Of K_2O.
Camus .	1 Ha	1744 Kg.	1744 Kg.	31·64 Kg.	12·76 Kg.	32·57 Kg.
Kellner .	1 Ha	4000 Kg.	7200 Kg.	84-109 Kg.	24-28 Kg.	45-79 Kg.
McDonnell	1 A	1575 lb.	1800 lb.	29 lb.	12 lb.	35 lb.

From these figures the percentages of the several substances in combined grain and straw are calculated as follows:

Author.	Per cent of N.	Per cent of P_2O_5.	Per cent of K_2O.
Camus . . .	0·907	0·365	0·934
Kellner . . .	0·75-0·982	0·214-0·25	0·204-0·705
McDonnell . .	0·8	0·355	1·037

As the roots, with the material they contain, remain in the ground after the harvest, their composition is not of permanent agronomic interest and has been little

studied. Still, the plant must have material for them as well as for the shoot, and this material remains tied up for a time. According to Herrero, the roots use more than half as much food from the soil as do the shoots during the seed-bed period, after which their proportional need decreases, becoming very little by the time of flowering.

With regard to the absorption of the food constituents during the different phases of the plant's development, we have analyses by Herrero and by Gile and Carrero, the latter made in Porto Rico.[1] The conclusion of the latter is that "the percentage of potash, phosphoric acid, and sulphur in the ash of the whole plant above ground decreased with the age of the plant, while silica increased and nitrogen in the dry matter decreased with the age." The detailed analyses, however, of plants at the age of 103 days (flowering) and 123 days (mature) show a great increase in the potash during this interval. The amount of iron was about constant after the first 26 days, the percentage of it therefore decreasing steadily. If this is generally true, it may follow that a neutral or acid soil reaction is important for rice only in the first stages of growth, when winter aeration and cultivation may have provided such a condition, and that thereafter alkalinity is harmless. This may also be one of the reasons that phosphatic fertilizers should be applied well in advance of seeding. Rice is not, however, so susceptible to injury by alkalinity of the soil as a consideration of iron alone might suggest.

Herrero's treatise is more complete, describing absorption during four stages, the seed-bed, rapid field growth, flowering, and fruiting. As the plant begins its life with a food store in the seed, which is rich in nitrogen and phosphorus, as compared with the vegetative structures, the percentage of these elements necessarily decreases as the plant grows. In the case of both,

[1] Gile, P. L., and Carrero, J. O., "Ash Composition of Upland Rice at various Stages of Growth," *Journ. Agric. Research*, 5. (1915), 357.

it increases again from flowering to maturity, while they are stored in the ripening crop. The absolute amount of both increases at all times, but the absorption of phosphorus slows down during the last stage.

Herrero's analyses are of the crop from 2·4 square metres of land. He calculates to a land unit of one *hanegada*, or 831 square metres, for which the crop was 692·4 kg., or 7436 lb. per acre, of rough rice. The corresponding absorption was :

	Kg. per Hanegada.	Pounds per Acre.
Nitrogen	15·350	164·76
Phosphoric acid . . .	8·225	88·34
Potash	12·488	134·12

It will be noted that these figures are far in excess of those already given on the authority of Camus, Kellner, and McDonnell, but that the greater absorption is fairly related to the greater crop. Comparing Herrero's figures with McDonnell's, the ratio of yields is 4·72, and of nitrogen absorbed, 5·68, which is a reasonable expression of the law of diminishing return. Herrero worked with the Italian *Chinese originario,* which is *Benlloch* in Spain and *Colusa* (1600) in California.

Treating the plant's maximum content as 100, Herrero tabulates his results as follows :

	Seed-bed.	Growth.	Flowering.	Maturing.
Duration . . .	..	52	22	22 days
Nitrogen. . .	0·94	74·90	85·51	100
Phosphoric acid .	1·01	75·80	93·10	100
Potash . . .	0·81	74·84	100·00	48·60
Dry weight . .	8·20	70·80	84·00	100

With regard to potassium, the analyses of Herrero

and of Gile and Carrero are contradictory. Neither is it possible at present to harmonize the results obtained at different times and places with potassic fertilizers. Herrero's conclusion, that potassium is needed in large amounts in the stages of vegetative growth, is supported by the fact that of the amount which is present in the plant only a small portion passes into the fruit. But this makes particularly remarkable the testimony of Novelli (see p. 315) and others at the Valencia Congress, to the effect that an abundant supply of this element does not so evidently influence the vegetative development as it does improve the crop.

To those familiar only with the old field crops of the Occident, and with the use of fertilizers only to maintain the general fertility of the land, the study of the progress of their absorption during the life of the plant may seem of academic interest rather than of practical value. But the study of rice opens up new problems. A very large part of the fertilizers applied to rice are so applied that they are available only at particular times. This is obvious where rice is transplanted and the seed-beds are fertilized. And after transplanting, it is general practice in China and Japan, and tends to become so in Spain, to apply fertilizers progressively, or at particular times, so that as little as possible may leach away and be lost. And in Italy, where most rice is not transplanted, the use of particular fertilizers after the rice is partly grown is well understood and practised.

Since the grain is removed from the land, while at least a part of the straw always remains on it, the distribution between these of the chief fertilizer constituents is of interest. Camus presents the summary facts as follows:

Percentage of	In Straw.	In Grain.
N	0·6	1·2
P_2O_5 . . .	0·14	0·6
K_2O . . .	1·6	0·25

Since, as already pointed out, plants exercise only a limited power of selection in their absorption of substances from the soil, they absorb minerals which are of no use to them. The ash of the straw and hulls of rice is very rich in silica, and according to Gile and Carrero the percentage of it increases throughout the life of the plant. It has generally been regarded as useless, or at any rate as unnecessary; but unpublished work of Miss Sommers, at the University of California, shows that extremely weak rice plants grow in solutions from which silica is completely excluded.

It is Japanese experience, endorsed experimentally by Nagaoka and Aso, that the presence of manganese is conducive to good crops. According to Castell,[1] manganese sulphate has proved deleterious in Spain and Italy, but the use of the almost insoluble carbonate has given good results. Castell concludes that a trace of manganese is a necessary part of the food of rice; but, on the whole, the evidence seems to indicate that it is a stimulant rather than an indispensable food element.

Many substances, toxic if present in considerable amount, are effective stimulants when sufficiently diluted. Roxas[2] has determined the molecular concentration, in which a number of these potential poisons stimulate the growth of rice most effectively, as follows:

Sodium borate	M/100,000
Mercuric chloride	M/ 50,000
Ferrous sulphate	M/ 1,000
Ferric chloride	M/ 10,000
Nickel sulphate	M/ 5,000
Zinc sulphate	M/ 1,000
Manganese sulphate	M/ 1,000

Copper sulphate and cobalt nitrate were also tested, with doubtful effect. The most conspicuous acceleration of growth was caused by ferrous sulphate and nickel sulphate. The experiments were performed with

[1] Castell Oria, E., "Emploi du manganèse comme engrais complémentaire dans la culture du riz," *Congrès Internat. de Riziculture*, Valencia, 1914, p. 158.

[2] Roxas, M. L., "The Effect of some Stimulants upon Rice," *Phil. Agric. and Forester*, 1. (1911), 89.

soil cultures in pots, watered with the solutions, which probably explains the rather high concentrations found beneficial.

Miyake [1] found that salts of the alkalis ($NaSO_4$, $NaCl$, $NaNO_3$, $MgSO_4$, $MgCl_2$, KCl, KNO_3, etc.) are "very poisonous" to rice when applied separately as tenth-normal solutions, but that the toxicity disappears in proper mixtures of the same total concentration. Potassium and sodium offset the toxicity of one another, and the toxicity of magnesium is well offset by the addition of a proper amount of calcium.

Excretions by roots, especially by those of grasses, are known sometimes to be injurious to other plants, and even to plants of the same kind. Villegas has shown that this will explain the poor growth of rice preceded by *cogon* grass (*alang-alang*, *lalang*). Peralta and Estioko [2] report injury by irrigating rice with water which has leached through soil in which other rice, or certain rice weeds, is growing. However, the differences in growth which they report lie within the limits of very possible error, so that it is unsafe to draw conclusions. A decrease in the size of successive crops grown on the same land has often been observed, but we do not know that root excretion is a factor in the phenomenon.

Correlations.—The treatment given to the plant determines both the rate of growth and the yield, and to the cultivator the latter is the main consideration. The close relation between vegetative vigour and yield of grain is generally recognized, and has been demonstrated quantitatively by Capinpin [3] with rice of pure lines, all of which showed a marked correlation between the weight of the straw and the weight of the grain of the individual plant. He did not find a close correlation between height or number of days of life and the size of

[1] Miyake, K., "Influence of the Salts common in Alkali Soils upon the Growth of Rice Plants," *Journ. Coll. Agric. Tohoku Imp. Univ.*, 5. (1914), 241.

[2] Peralta, F. de, and Estioko, R. P., "A Tentative Study of the Effect of Root Excretion upon . . . Lowland Rice," *Phil. Agric.*, 11. (1923), 205.

[3] Capinpin, J. M., "Correlation within Pure Lines of Rice," *Phil. Agric.* 12. (1923), 3.

the crop; but Peralta found a clear relation between length of life and area of leaf surface, and between the height of the plant and the yield.

The subject of correlations as between varieties has been studied in the Philippines, using a sufficient number of varieties to give a measure of probable validity to the results, by Jacobson[1] and Vibar.[2] Their collective conclusions are summarized by Mendiola as follows:

I. Positively correlated:

(*a*) Correlation decided:
- Yield and tillering.
- Yield and days to maturity.
- Days to maturity and length of longest leaves.
- Days to maturity and weight of straw.

(*b*) Correlation marked:
- Yield and length of culm.
- Yield and length of panicle.
- Yield and number of nodes in the panicle.
- Yield and length of grains.
- Days to maturity and number of grains in the panicle.

(*c*) Correlation slight:
- Yield and number of spikes per panicle.
- Yield and weight of leaves.
- Yield and length of leaves.
- Yield and weight of straw.
- Days to maturity and length of culm.
- Days to maturity and length of panicle.
- Days to maturity and number of nodes per panicle.
- Days to maturity and width of leaves.

(*d*) Other positive correlations:
- Days to maturity and length of grains.
- Days to maturity and number of nodes per culm.
- Days to maturity and grain dimension ratio.
- Length of culm and number of its nodes.
- Number of internodes and their average length.
- Length of culm and length of rachis.
- Length of rachis and number of its branches.

[1] Jacobson, H. O., "Correlative Characters of the Rice Plant," *Phil. Agric. Review*, 9. (1916), 74.

[2] Vibar, T. N., "Variation and Correlation of Characters among Rice Varieties," etc., *Phil. Agriculturist*, 10. (1921), 93.

II. Correlation absent:
- Yield and number of grains per panicle.
- Days to maturity and number of culms.
- Days to maturity and number of spikes per panicle.
- Length of grain and number of culms.
- Number of culms and grain dimension ratio.
- Number of culms and their average length.
- Length of culm and length of grain.

III. Correlation negative:
- Width of grain and days to maturity.
- Number of culms and number of grains per panicle.

Some of these conclusions are doubtful or of limited applicability; it is not true, for instance, of varieties cultivated in the United States, that those with long grains characteristically yield heavy crops. A considerable part of these relationships are obviously physiological in their character, as short-lived rice, for example, has not time to accumulate the material for a heavy crop. Others are presumably genetic, the characters being inherited in groups; it is to the study of these that the statistical methods employed by Jacobson and Vibar are regarded as particularly applicable.

"Glutinous" rices, as a class, have soft and pliable straw, which makes their straw more valuable, but entails the risk of lodging.

A statement of further results of the genetic study of rice is reserved for Chapter IV.

Flower and Fruit.—The main axis of the panicle is a continuation of the culm or stem; it is called the peduncle below the lowest node of the panicle, and the rachis above this point. The rachis bears no leaves, but is divided into internodes by nodes, from which the branches spring, either singly or in whorls. The branches may be simple or branched in turn, and each final branch usually bears several spikelets. The average number of spikelets in a panicle varies with the variety. In Jacobson's report of 717 varietal tests, 5 fell in the class with an average of 50 grains per panicle, and one showed an average of 478 in one year.

The spikelet consists of a single flower accompanied by other structures which, strictly speaking, are not part of it—namely, the glumes. It is borne on a short stalk called the pedicel. In varieties which, when mature, have straw-coloured glumes and whitish kernels, the glumes are generally entirely green when the panicle emerges from the boot-leaf, but this rule is not without exceptions. In *French*, for example, the tips of the palea and lemma are red at first, but this colour fades out before maturity. Varied colourings at flowering time, but not necessarily permanent, commonly mark the glumes of those varieties which, when mature, have coloured glumes or kernels.

The flower, which is enclosed by the lemma and palea, just as is the kernel at maturity, consists of two small bodies called lodicules, one on each side at its base; six stamens with short filaments and linear, yellow anthers; and a pistil with a small ovary and two sessile stigmas, which are long and feather-like.

The rudimentary panicle can be detected at the summit of the stem at about the time that the stem begins to elongate rapidly. The rachis grows rapidly before the peduncle does, as is shown by the figures already given in connection with growth. The uppermost spikelets develop first, and, in each spikelet, the outer glumes are the first parts to reach their full size, followed in succession by the inner glumes and the parts of the flower proper. While they are growing rapidly, before they emerge from the boot, all parts of the panicle are white. The awns, if present at all, are fully developed before the panicle emerges.

The panicle may emerge completely from the boot during a single day; usually the process requires several days, sometimes as much as a week. Flowering, by which is meant the exposure to view of the flower itself, follows, the spikelets of a panicle flowering in succession, from the top downward. In variety *skrivimankotti*, the subject of extensive genetic work in Java, the panicle emerges in a single day and the flowers all

open before night. The other extreme is reported by Jack, as to rice in Malaya: "The young colourless flowering panicle thrusts itself through the ensheathing leaves, the individual flowers beginning to open about ten days later. The flowers mature from the top of the spike downwards, a period of about six days being necessary to ripen all the flowers on each panicle." The last process requires six to ten days in a Javan rice reported by Breda de Haan.

The exposure of the flowers is accomplished by the spreading apart of the lemma and palea, enough to form an angle, commonly, of 30° or less. The opening movement is supposed to be caused, as in other grasses, by a swelling of the lodicules; and the closing, to result from the wilting of these, following their exposure. The flowers open mostly, and in the case of many reports, entirely, during the forenoon, and usually remain open for a period varying from 35 to 90 minutes. Mendiola reports careful observation of the flowering of very many flowers of three varieties, the duration averages falling very near together, to wit: for the time consumed in opening completely, 6·5 to 6·9 minutes; and for the time they remained open, 54·7 to 59 minutes.

As the flowers are about to open, and open, the filaments elongate rapidly, becoming, in the course of a few minutes, longer than the lemma, so that the anthers are carried outside. They may remain stiff for a time, or become pendant almost at once. Counts by Mendiola's students show from 463 to 915 pollen grains in an anther. These are set free either just before the flower is exposed or while the spikelet is opening, rarely later. Cross-pollination is therefore possible, but self-pollination is far more certain. The wind rarely carries any pollen farther than six feet. When plants of different varieties are growing close together, so that cross-fertilization can be detected if it occurs, the extent of it varies from 0 to 1 per cent, or rarely more, although 25 per cent has been reported.

The Indian wild rices[1] do not as a rule discharge the pollen until some minutes after the extrusion of the anthers. In these rices the crossing amounts to about 7·9 per cent.

Crisostomo,[2] who studied a large number of Philippine varieties, found that in them the time from flowering to maturity varies from 11 to 69 days, the average being about 33. These extremes cover the range reported elsewhere. During the first few days after pollination, the endosperm in the single ovule grows rapidly and reaches its full length, after which its other dimensions increase slightly. Its contents are at first liquid, and filled with white, starchy material. In this stage the crop is said to be "in the milk." As more material passes into the endosperm it solidifies and hardens, passing through the "dough" stage, soft and hard, before the crop is ripe. In some, mostly valueless, varieties, the rachis and its branches are able to remain erect; but in most the weight of the crop causes the rachis to droop and the branches to spread. The glumes and the wall of the ovary, which continues to enclose the seed, dry up, and assume their final colour. The anthers, left outside when the palea and lemma close together after flowering, soon fall off. And when the fruit is mature, all trace of lodicules, filaments, and stigmas has practically disappeared.

[1] Roy, S. C., "A Preliminary Classification of the Wild Rices of the Central Provinces and Berar," *Agric. Journ. India*, 16. (1921), 365.
[2] Crisostomo, M., "Cultural Notes on Upland Rice in the Philippines," *Phil. Agric. and Forester*, 3. (1915), 111.

CHAPTER II

CLIMATE, SOIL, AND WATER

We have next to deal in a more directly practical manner with the relations of rice to its environment. As to the rice plant itself, what is to be said here ought to be an application of the facts developed in the preceding chapter. In part, it is this. The restriction of rice culture to fairly warm regions is related to its probably tropical origin and its inability to grow at low temperatures; the particular suitability of heavy soils to rice culture is associated with its remarkable ability to use ammonium better than nitrate nitrogen, and both are correlated with its original swampy habitat. At present, however, our knowledge of the botany of the plant lags behind its culture. It is only here and there that our knowledge of its physiology throws a useful guiding ray on agronomic practice. One fact in particular, already given emphasis, requires it again, for the proper appreciation of almost everything now to be presented—that rice is a vast number of varieties which differ widely in their demands upon, and response to, the environment. The qualification that they are true of some rice, but not necessarily of all rice, must be understood in connection with very many statements where its repetition would be wearisome.

But our real interest is in rice as a crop, not as a mere plant. As a crop it has a more or less independent set of relations to climate, soil, and water, all of which work together to determine the practicability of means

of cultivation and harvest, and its relief from competition with weeds and from pests, quite independently sometimes of their direct effects upon the rice plant. This group of relations must receive no less consideration here than the direct ones of the plant itself, which latter, indeed, are of practical importance only as they too guide agricultural practice. There is a group of still more indirect relations which do not require explanation here; these are the many ways in which the same environmental factors which control rice culture also and at the same time act upon the men who grow or consume it—by influencing their bodily vigour, their economic strength, and, in the long run, their social organization.

CLIMATE

Heat.—Although but little subject to control, as one may be able to choose when and where he will plant rice, heat is the environmental factor best understood in its relation to rice, partly because it is the factor most easily sensed and most accurately measured. It is assumed to be the factor which determines the general limits of rice culture, in latitude and in altitude.

Rice culture reaches to about 40° of north latitude in a number of places, but nowhere, as an industry, passes 44°, except a short distance in Italy. Its limits are: Central Hokkaido, but the southern part of the island raises little rice; northern Korea; central Manchuria, but the southern part has not a typical rice industry; Bokhara and Khiva; the southern shores of the Caspian, where rice is the staple crop; Bulgaria, which raises a few thousand tons; northern Italy; the lower valley of the Rhone, where, however, it is no important crop; North Carolina, where very little is grown, though it will thrive; Arkansas; and the head of the Sacramento valley. Toward the south, crops mature in Natal, Victoria, and New South Wales, and well south in Argentina; but as a crop it has no standing

in Australia, nor below southern Brazil; nor probably at present south of Zambesia, though the distribution of what can be called crops in Africa is uncertain beyond the influence of European plantations.

In altitude, rice has been grown in the Himalayas up to at least eight thousand feet.

As has already been stated, the critical temperatures are so different in the cases of different varieties that some varieties can be grown successfully and without difficulty in lands (Japan, Korea, Italy, Argentina, California) where the great majority will not reach maturity. It is true of many varieties, but may not be of others, that, for such thriftiness as permits their industrial use, a higher temperature is necessary during the period of most active vegetation, than for the earlier stages of activity or for the ripening of the grain. Fort[1] says: "On dit que le riz a besoin d'une température de 12 à 13 degrés pour germer, de 22 à 24 pour fleurir et de 19 pour mûrir; mais il ne faut pas perdre de vue que certaines variétés sont plus exigentes en chaleur que d'autres." Careful observations on this subject have been made only on varieties which are cultivated where the temperature must be reckoned with, as in Italy, Japan, and California, but not upon those of the equable tropics, which, whatever the exact reasons, will not produce a crop in the northern countries.

High temperatures have been said to injure rice; but the statements are not accompanied by evidence, and I doubt such injury except as insufficient water may more reasonably be held responsible. 37° C. is a high maximum in the rice-growing tropics, and is fine for rice. Temperatures well above 40° are common in California, and are depended upon to rid the fields of water grass. If prolonged and uninterrupted, as they can be in laboratory experiments, such temperatures might injure rice; but for such duration as occurs in the field the grower welcomes them.

[1] Fort, E., "Choix et sélection des riz de semence," *Congrès Internat.*, Valencia, 1914, p. 109.

Too low temperatures may:

(1) Kill the plants. But there are varieties in Korea and in the mountains of Luzon, and probably from Yunnan to Persia, which are normally exposed, as seedlings, to temporary freezing.

(2) Destroy vitally important structures. Frost during or soon after flowering blasts the crop (*wataribune* and others) in California, without killing the plants.

(3) Arrest the plant's activities, without doing any irremediable harm, except as delay may involve exposure to injury. Cold spells in spring may make growth imperceptible for many days, if any growth occurs at all; but the seedlings remain ready to take advantage of warmer weather when it comes. In California two fields planted respectively in mid-April and mid-May may look alike in August, but the former produces a heavier crop. In connection with much water, cold weather may result in an excessive mortality of the seedlings immediately after germination, resulting in a poor stand. Marcarelli[1] says that the period of greatest susceptibility to injury by cold (not necessarily that when the highest temperature is needed) is that of most active tillering. Bad weather at this time checks the root development as well as the stooling, and is likely to result later in the lodging of the crop.

Marcarelli also states that great daily fluctuations of temperature are intolerable; but here again account must be taken of varietal differences. It is probably because of the cold nights that *Honduras*, not at all a late rice in Louisiana, fails to mature reliably in California. But no such extreme sensitiveness is shown by *wataribune*, a Japanese rice later than *Honduras* in the south; nor by *Colusa*, imported from Italy and supposed to be originally Chinese; nor by *French*, a Piedmont rice believed to be ultimately Japanese. Because of the cold nights, maize is not an important California crop. Its growth in height is expected to occur chiefly in the night, so that cold at that time may be especially harm-

[1] In *Giorn. di Risic.*, 8. (1918), 7; *Internat. Rev.*, 9. (1918), 539.

ful. But rice, supplied as it is with water, is not so restricted in its elongation to one part of the day, and might therefore be expected to be comparatively immune to injury by cold during those particular hours.

Calculations of the total temperature required to mature a rice crop, figured by adding the daily mean temperatures throughout the growing season, have been made in Spain and Italy. Marcarelli puts the requisite sum at 3500° to 4500°. Fort says that *Chinese* requires only 2400°; *Novarese* and *Ostiglione*, 2800°; *nostram*, 3000°; *Japanese* and *giant*, 3200° and 3700°. My own observation of two of these varieties shows that such figures are not valid independently of other conditions; for *Novarese* matures before *Colusa* (*Chinese originario*) in the same California field. Our knowledge of the time of ripening is still entirely empirical; that is, we have learned by experience when to expect the varieties in use to flower and ripen in particular places; but we do not know what part the several effective outside factors —total heat, distribution of temperature in time, total insolation and its distribution, water, and plant food, available and absorbed, acting by themselves and in their inter-relations—play in determining these dates, any more than we understand the complex of internal reactions through which they make their influence felt. These are no merely academic questions; as they are solved, we may confidently expect to handle the factors subject to our control more skilfully than is now possible. As to low temperatures, aside from what has already been said, about all that we really know is that prolonged cold delays flowering and ripening.

The statements already made as to the geographical limits of profitable rice culture likewise fairly summarize our definite and practical knowledge of the subject. But such limits may change. Rice has been ripened, without profit, in Illinois and Indiana, and is said even to have done so in London. The stories of 50- and 60-day rice, however questionable, have not been disproven. For such a period in summer, Stockholm is warmer than

many rice lands. The winter rice of Korea has never been well tried, and the Luzon mountain rice not at all, as material for increasing the range of rice culture.

The California method of controlling the worst of the local weeds, barnyard grass, is an example of the dependence of cultural practice upon temperature. This is a cosmopolitan weed, and the drowning of weeds is world-wide practice; but the completeness of destruction, however dense the infestation, seems to be unique in California, and is dependent upon very high temperature, certainly above 37°, and perhaps above 40°.

Light.—Light is indispensable for the vegetative activity of green plants, and among plants rice is certainly to be classed as a "light-loving" species. There is no reason to suppose that, having sufficient water, rice can have too much light. In Egypt, Sindh, and California the sky may be cloudless throughout the rice season, and the rice thrives. Prolonged cloudy weather is everywhere recognized as detrimental to it, delaying its development at all stages after germination, and making it susceptible to disease and other injury. Marcarelli says that 140 to 170 days of clear or partly clear sky are necessary for a good rice crop in Italy (*originario*). Shading by trees or higher weeds, such as the cat-tail, is very bad for the crop. A summation of the hours of full insolation would probably be fully as significant as a sum of temperatures in defining the climatic conditions of rice-growing.

It is probable that the length of day has an important influence on the sequence of activities in the later part of the life of the rice plant, in such a way that a given variety tends to flower when the days are of a certain length, and to mature about a fixed number of days later. This proposition is amplified in the discussion of varieties.

Outside of its importance in the production of carbohydrate food, and perhaps as a regulator, light is important in rice culture as a source of energy to evaporate water, causing the stomata to open and water to evapor-

ate and leave in the leaves what it brought in solution; and helping the fields to dry for the harvest. Sun-cracking, which sometimes materially lowers the quality of early rice in northern countries, results from excessive insolation, though heat is probably the physical factor directly responsible.

Wind.—Gentle movement of the air is favourable to the vegetative vigour of rice, assisting in the movement of gases and preventing saturation of the air about the leaves. Violent wind is dangerous, sometimes wearing down the dikes by wave action, and causing lodging and shattering as the crop ripens. Typhoons, both by the force of the wind and by causing floods, are one of the greatest dangers to which rice is exposed in Japan, China, and the Philippines. The choice of varieties which do not lodge or shatter badly, and the retention of deep water as late as is practicable, are means of minimizing this danger.

Water.—The relation of any plant to water is a complicated one, and that of rice is especially so. Besides being itself an essential food, the solvent and conveyer of other foods, and a substance which must be physically present in the plant in large amount, it is the factor of the environment which naturally varies most, and is the one most subject to artificial control.

Atmospheric humidity is never absent, but it varies from very little to all that the air can hold. Well-irrigated rice never suffers injury from dryness of the air. In California, Sindh, and Egypt the relative humidity, by day, may be below 40° for long periods. Some leaf-tips are killed, and the active life of individual leaves may be shortened. But, on the whole, the rice thrives in such weather. The old idea that irrigated rice requires a moist climate was certainly incorrect; constant high humidity is more likely to make heavy crops impossible, although field experience can hardly prove this, because constant humidity is in nature accompanied by cloudiness.

Great atmospheric dryness can doubtless injure

upland rice. Where rice is not irrigated, its power to endure prolonged high temperature and intense insolation, as well as very dry air, is naturally much more restricted. In particular, such rice is of course dependent upon occasional or frequent rain. All of these differences restrict the geographical distribution of upland rice. The cultural treatment must also be appropriately different, aimed in most places at the conservation and availability of ground water. And, more than anything else, the choice of varieties for upland culture is much more limited; most varieties will thrive under irrigation, but most lowland rices cannot endure upland conditions.

A considerable rainfall is sometimes stipulated as a necessary condition for rice-growing, and much rice is raised where it is such a condition. As probably more than half of the Philippine rice is grown, an average of a centimetre a day throughout the growing season is considered necessary if crops are to be good; and this must be well distributed, without intervals of more than ten days. And even then, for lowland rice the soil must be quite heavy and impervious. This demand for at least 1500 mm. of rainfall, for somewhat early rice, may be contrasted with Marcarelli's dictum that the rainfall in Italy, from April to September, must not exceed 200 to 250 mm. The explanation is of course that it is not specifically rainfall, but merely water, which rice requires. Where irrigation facilities are perfect, no rainfall is needed; where irrigation is not provided, rice must depend upon rain, and the accompanying cloudiness is then a necessary evil.

In ways which constitute a variety of local problems, rain determines the time or manner of cultivation. The grower may wait for rain to soften a majority of the acres to be planted with rice, because he is unable to break the ground, dry. But in the United States we wait for the rain to desist, because with our facilities we cannot work the adobe wet, and would not if we could. According to local conditions, rain is a slight or a very

great menace to rice, as an impediment to the harvest; it adds to the cost of the operation, lowers the quality of the product, and sometimes results in huge total losses.

The danger that there will not be rain, and the less general danger that there will be rain—of which, in different places, one or the other is the outstanding peril—are responsible, far more than any desire to economize time for any reason, for the cultivation of early varieties. These are, in general, inferior to the later ones in both yield and quality; but these disadvantages are submitted to for the sake of greater certainty of harvesting, easily and completely, all that the grower looks for when he plants.

Alone among the world's great crops, rice grows typically in a field of standing water. Whatever is unique in rice culture, centres naturally around this basic feature of it. Ideally, and on a vast scale in practice, this water is provided and regulated by the grower; irrigation is *the* technique of rice culture. Where water can be applied and cold does not prevent the growth of rice, other climatic features at most determine how water must be used, or what varieties may be grown. And irrigation is not merely adapted to climate and variety; on the scale on which it is practised with rice, it modifies the climate. Water so dominates over other climatic factors that, with good irrigation facilities, rice must be recognized as the safest of the world's great crops.

At this point, in advance of the presentation of the diverse practices of rice culture, it would be impracticable even to enumerate more than the most remarkable correlations between water and these practices: its relation to such unique operations as puddling the soil and transplanting the seedlings; the inability of rice to use nitrate nitrogen, and the consequent use of ammonium fertilizers; the specific weeds and the use of water to subdue even such as cannot grow without it; its responsibility for diseases and pests, and its use in their control; and the application to rice of a capital

investment far greater than any other annual crop requires.

Between irrigation water and flood water no line can be drawn. Everybody knows that Egyptian rice depends upon the flood waters of the Nile. But few realize that just such annual floods in the delta lands of the Mekong, Menam, Salwyn, Irrawaddy, and Brahmaputra-Ganges serve each year to produce more rice than Egypt has produced in all past time. Choice of variety, preparation of land, and method of culture are adapted in each spot to the depth of water anticipated, so that a mere wetting in some places, and inundations exceeding even 15 feet in others, are alike serviceable or at any rate harmless. Unseasonable or excessive floods are destructive. These are comparatively local; still, they are second only to the absence of sufficient water, as factors which cut down the total of each year's crop.

SOIL

With suitable use of water and of fertilizers, and choice of variety, any soil which will produce any crop will produce rice; this is not a platitude, but a matter of real importance in places where rice is the particular crop men want and the available land is all in use. They then make soil for rice where there practically was none, or work over and modify whatever unsuitable soil may exist, and do this with care and effort hardly ever exercised for the sake of any other crop.

The soil which will produce the best crop of rice at the least cost is rich, smooth, mellow, and easily worked —the same formula used to describe best soils for all crops. And as to upland rice, where it has a place in the permanent use of the land, whether judged by itself or as one of a sequence of crops, it does not, so far as we know, make particular demands upon the soil, nor fail to respond like other standard crops to the elements of merit which cause good soils in general to be so regarded. It endures less desiccation than do many

crops, responds better than do some to the presence of considerable humus, and endures saturation with water better than do most.

The growing of typical, lowland, or irrigated rice, however, involving an investment in the preparation of the land and the provision of water such as no other great crop requires, is very permanent agriculture, and the important question is not as to the soils which will produce *a* good crop, but as to the production of a long succession of good crops. Taking account of the permanency with which land must be devoted to lowland rice, and of the cost of water and the risks involved in its waste, it can be said flatly, and as a remarkably invariable rule, that lowland rice is a plant adapted to heavy soils, and that only heavy soils are by their character suited to rice.

This follows from the semi-aquatic origin of the plant. It follows from what has already been said about its need of water, its ability to do with little oxygen, and its preference for ammonium over nitrates; for heavy soils hold water well, much water excludes much air from the soil, and the absence of air makes oxidation imperfect. There is also good economic reason for preferring heavy soils, already suggested. Irrigation water is expensive, and rain is an unreliable source of water to be impounded; and water is much more securely held in and on heavy soils than in and on light ones. The same considerations which make heavy soils wanted for rice, also make it desirable that there be, at a depth below the reach of the roots, but not too much further down, an impervious substratum—subsoil or hard-pan. Water which percolates or seeps through the ground, downward or laterally, is wasted; and whatever it may take with it is also lost to the rice. The soil through and from which the least water can get away is in that respect the best.

Also, heavy soils, retentive of water, are soils composed of very fine particles. The rice roots form under water no system of root hairs presenting a great surface

for the absorption of water and dissolved salts, as do the roots of most crops growing in drier soil. The intimate contact of the surface of the root hairs with the surface of the soil particles is supposed to play an important part in effecting the absorption by the plant of some of the substance of these particles. Rice forms very fine, apparently absorbing roots; but these develop no such area of surface as a good system of root hairs affords, and the surfaces of the finest roots are not plastic like the walls of root hairs, so that they can fit against the particles of the soil instead of merely touching them. In the case of rice, then, the actual contact between root and soil is far less extensive than in the cases of most plants; but the extreme fineness of the particles of really heavy soil makes this contact much more ample in area than it could be if the soil were coarser and lighter.

For the more accurate definition of what constitutes a heavy soil for rice purposes, Camus[1] says that the best in the Philippines must contain at least 40 per cent of clay, with particles less than 0·002 mm. in diameter, and 20 per cent of fine silt, with particles less than 0·01 mm. in diameter, and some humus. Jack[2] gives the following table of the mechanical composition of some Malayan soils, classified according to demonstrated value for rice:

Locality.	Humus.	Clay.	Fine Silt.	Silt.	Sand.	Class of Land.
1. Krian	4·0	57·7	20·9	15·3	2·0	First.
2. Kedah	..	28·2	58·1	10·5	3·2	First.
3. Kedah	..	31·1	31·7	27·2	10·2	First.
4. K. Kangsar	..	26·2	50·4	15·3	7·1	First.
5. Jelebu	4·0	17·5	32·8	16·3	29·4	Second.
6. Kuala Piloh	..	17·6	28·1	16·6	37·7	Second.
7. K. Kangsar	..	18·6	27·4	14·0	40·0	Second.
8. Jelebu	1·6	19·1	30·2	7·3	41·8	Second.
9. K. Kangsar	..	6·9	10·2	14·0	68·9	Third.
10. Kuan (peaty)	12·8	28·9	34·6	15·6	8·1	Third.

[1] Camus, J. S., "Rice in the Philippines," *Phil. Agric. Review*, 14. (1921), 7. See p. 15.
[2] Jack, H. W., "Rice in Malaya," *Malayan Journ. Agric.*, 6. (1923).

Jack's limits on the several constituents of first-class rice soil are: humus, 3 to 7 per cent; clay, 25 to 65 per cent; fine silt, 20 to 60 per cent; silt, 10 to 25 per cent; and sand, 2 to 10 per cent.

As already stated, a rich loam soil will, with sufficient water, raise *a* crop of rice as heavy as can be desired. But the relatively free seepage of water through such soils results in a leaching out of their soluble plant food. A succession of rice crops on such soils results, therefore, in their rapid impoverishment. There are many crops for which light soils are better than heavy ones, and their use for rice is uneconomical. Instead of improving them for other crops of a rotation, as rice does to most heavy soils, it is likely to leave light soils poorer, and to improve them in no way except by freeing them from the weeds of dry crops.

As to the chemical constitution of the soil, the plant's need of certain food elements has been explained in the preceding chapter, and experience with fertilizers in a number of lands will be described in Chapters V., VI., and VII. The gap between these can be bridged here very briefly. No treatment of the subject can be really general, because soils vary so widely, and in minor degree because varieties differ in their wants. Fort says that an ideal rice soil must contain one part in one thousand each of potassium, phosphorus, and nitrogen; but this expresses a Spanish point of view, describing a soil good if treated in the Spanish manner. The availability of the elements is never so complete that such a soil would produce good crops without the use of fertilizers. All Spanish rice soil contains several times this amount of potassium. Yet it is the Spanish practice to apply potash artificially, and phosphorus and nitrogen are always applied freely in Spain. Of the soils represented in the preceding table by Jack, the total potash content averaged 0·508 per cent in those classed first, and 0·176 per cent in those classed second. The total phosphate was respectively 0·067 per cent and 0·039 per cent; and the nitrogen, 0·240 per cent and 0·151 per cent.

Tropical soils are in general poor, if judged by chemical analyses.

It is only with qualifications that any soil can be called perfect, or best, or ideal. For example, the soil which will produce the greatest aggregate crops over a considerable period will not produce the safest and most easily handled crop the first year. A spot where sheep have been herded, and the sites of burnt straw stacks, produce wonderfully luxuriant *wataribune* the first year, on which the grain ripens late and irregularly, and is not harvestable; but during the following years these spots produce the best crops in the field. Further, if the ideal soil for a single crop be defined as that which will produce the heaviest yield, it must be noted that the amount of nitrogen necessary to accomplish this result will also make the crop late and predispose it to lodge. Ayyangar [1] says that if the wind blows the scum on the water to one corner of the paddy, the result is increased fertility and later ripening there. And if expense of harvest and danger of loss by lateness (by typhoon, pest, drought, or the onset of winter) be ignored, it is still to be observed that quantity is not the sole consideration. For illustration, *bomba* is the most prized Spanish variety, selling for a third to a half more per unit of weight than *amonquili* or *Benlloch,* but yielding less heavily. The richness in nitrogen which will produce the best crop of *Benlloch* will usually destroy the crop of *bomba,* by promoting excessive luxuriance and subjecting it to *falla* (blast). There is also a relation between the climate and the degree of soil richness which will produce the best results; but the published evidence on this point does not appear harmonious, and more knowledge of the behaviour of the plant is needed before this relation can be defined.

Taking any mechanically satisfactory soil, the grower can remedy its chemical deficiency, and sometimes correct its excesses, by the due use of fertilizers. The

[1] Ayyangar, G. N. R., "Some Rice-breeding Experiences," *Agric. Journ. India,* 16. (1921), 156.

specific applications required to accomplish this are purely local problems. On new land in California, no fertilizer will return its cost. The same was found true, as a rule, at the Philippine College of Agriculture, and it is probably so in most places. Likewise, on new land, the choice of variety and the method of treatment should be adapted to its abounding fertility. After a single crop, in California, the application of barnyard manure pays. In the few years of experience, it has already become evident that the prospect of profit by the addition of other fertilizers is growing, year by year. And in no one of the old rice countries notable for high yields would any grower now think of raising a crop without appropriate annual additions to the supply of the plant's food.

This is not necessarily because the soil contains very little of the elements it pays to add. The Japanese find it expedient to apply phosphorus to soils which chemical analysis shows to contain as much of it as will be removed by rice in two hundred years. Chemical analysis of the soil should be a better guide to the choice of fertilizers for rice than for most crops, because in ordinary rice culture there is no effective variation in the amount of water in the soil. Still, local experience, preferably on small plots on the grower's own field, is the only safe business guide, both as to the choice of fertilizers and, still more, as to the amount. Time and method of application, and variety of rice, have also to be decided locally.

Without at this point giving the results of any experiments with fertilizers, which would have only a local significance, and some of which will be reported in later chapters, it can be stated as the general conclusion from such experiments that for continuous rice culture it pays to use phosphatic fertilizers freely, the best form depending upon soil conditions and the immediacy of the results desired; that the liberal addition of nitrogen is also profitable, whether as green manures, or in some other organic form, or as ammonium sulphate; that it usually pays to apply potassium, and that the most generally satisfactory inorganic form is the sulphate.

There are other substances, not usually considered needed as food constituents of plants, or of which enough is present to satisfy the demand for them as food, which it still sometimes pays to add. Manganese, for example, seems to be well worth applying in some places, but not in others. Rice does not thrive on very acid soils, but the decomposition of organic matter where oxygen is not abundant tends to develop acidity. To remedy this condition, where it exists, it pays to apply lime; but a very little lime in the soil satisfies the demand of rice for it as food. Because they accentuate the tendency of the soil to become acid, the chlorides of ammonium and potassium are not usually good fertilizers. The unsuitability of peaty soils for rice is presumably due to their acidity. Rice thrives on some decidedly alkaline soils, which are improved for other crops by rice culture, as the water removes some of the alkali. Some varieties endure a very considerable concentration of common salt.

In a rice field, the land enclosed by each dike (what is variously known as a paddy, check, cut, etc.; many names for these divisions of the field have been used in English) should be as level and even as it is practicable to make it. If the inequalities of level are material, they result of course in unequal depth of water, which in turn has a variety of evil consequences, depending upon whether the water is so held that the injury is where it is deepest or where it is most shallow. Differences in level between adjoining paddies are relatively unimportant; but, if considerable, they involve waste of land, require especial care in irrigation, and make the use of machinery impracticable.

In appraising for rice culture land not yet in rice, flatness and evenness are obviously primary considerations. On the lowland rice land in the Philippines as a whole, the cost of converting it to paddy land is estimated as more than the value of the land itself before its conversion; this is not true of every parcel, but is true of much land which was in real demand for other crops

before it was devoted to rice. In many other parts of the East, the condition is the same, in spite of the cheapness of labour. The cost of terracing increases rapidly with departure from levelness. Even more serious than this initial cost may be the smallness and irregularity of the paddies, which necessarily result if the land is very sloping or broken up. For machinery to be used, in cultivation or harvest, it is absolutely necessary that the land be nearly level and not much broken. Absolutely level land, on the other hand, offers difficulty in both irrigation and drainage; but perfectly level land is not often found. In California, land which will be cut by 3-inch contours into checks 30 to 60 yards wide is considered to lie perfectly, having regard at once to irrigation and drainage and to ease of cultivation and harvest. Where irrigation must be with smaller heads of water than are usually available in California, the checks must be smaller, but this can be arranged if necessary by dikes crossing the contour lines. Where machinery is not used, the paddies may be smaller without inconvenience; but the extreme smallness common in the Orient is recognized as an evil, worth correcting even at considerable cost.

CHAPTER III

DISEASES AND PESTS

The pests and diseases of rice are taken up at once for the world as a whole, in spite of the fact that the most of them are of rather limited distribution, so far as known, and might therefore be deemed to be of correspondingly limited interest. The reasons for this treatment are that the actual distribution of many of them is probably much wider than is shown by published reports; and that if the distribution be indeed limited, they are still potential enemies beyond their present limits, more likely to be kept from spreading if they are generally known as such. The supposed freedom from enemies of California rice, for example, is not quite real, a spot, a mildew, and a flea-beetle, at least, being present; and so far as it is real is a condition worth preserving with any necessary effort, and more likely to be preserved if the enemies elsewhere are well known.

The necessary protective service is being given to American rice by the United States plant quarantine, which prohibits, without recourse to permission for admission under whatsoever restrictions, the importation by private parties of any rice, from a large part of the world, except for consumption. But the same care is not everywhere taken, and no quarantine can be trusted to be permanently perfect. Many of the diseases and pests are therefore potential enemies of the rice of every country. Various diseases would be harder to exclude than weeds; but one very serious weed was

admitted, from Japan, to both Italy and California about a decade ago.

It is a general principle that the more extensively and continuously any crop is planted, the more it is likely to be the prey of epidemic diseases and pests. Rice is perhaps the most widespread of crops, and is certainly the crop by far most continuously planted over single great areas. It is therefore remarkable that it has never, so far as we know, been destroyed as an industry of any country, as coffee has been wiped out in several, and is not even known to be generally subject to any such serious damage from an enemy as wheat, for example, has suffered from its rust. The explanation is probably not that rice is more immune than wheat, in its nature, though this is possible; but is rather to be found in the different methods of culture. Commonly transplanted, and always harvested by hand where its culture is old and intense, rice has been comparatively easily and naturally guarded against epidemics, by reasonable care and without recourse to any scientific methods, such as disinfection or the use of the enemies of the pests.

Also, the enemies of rice have their enemies in turn where rice is native. The first local epidemic pest which drew the attention of the Philippine College of Agriculture disappeared suddenly, just when it seemed irresistible, overwhelmed in turn by a parasitic fly. Let any one of a number of the Oriental pests, held down at home by hand culture and harvest and by their natural enemies, get a footing in rice harvested by machinery, where they have no developed enemies of their own, and it may well destroy the local rice industry. Whenever such a pest makes its first appearance elsewhere, there should be an instant attempt to import its natural enemies, other combative methods being used while these can be imported.

Rice, like man and other living things, may be unhealthy, and may die without being attacked by any other living thing. Lack of water does more damage to

rice than do all its living enemies combined. Next to that from too little water, it probably suffers most injury from too much water; it is probably no unusual year when the damage by storms and floods in the Orient exceeds the total rice production of Italy or the United States. It suffers from wind; and while the wind is beyond control, the damage it does can usually be limited. It practically never produces the maximum possible crops, because it is inadequately or improperly nourished. Because of improper treatment, it may be spindling and unproductive, may "run to leaves," and mature too late for harvest or not at all, or ripen too unevenly to harvest well. All of these troubles of rice are functions of the cultural treatment, and need no further discussion at this point.

Weeds, likewise, however real a pest they are, are subject to cultural control, and as a matter of convenience will be treated at length in connection with the handling of rice in California, and briefly elsewhere as may be necessary.

Every grower must in practice be his own rice doctor or have none at most times. His eye should tell him from day to day whether or not his field is thrifty. If in doubt, he can have recourse to measurement of growth; but most farmers will not do this, and if the condition is at all bad it is unnecessary. If the condition is bad, a *prompt* diagnosis, and correction if possible, is the only chance. For rice usually has at best no more time than it needs, and is likely to mature a bad crop instead of delaying it. As a general proposition, the most that can be hoped for is to mitigate the damage, by the time injury is evident, unless the application of more or less water is a promising remedy. But a correct diagnosis will very generally guard the grower against the same trouble another year. If a real disease or pest is present, or reasonably suspected, a Government expert can almost anywhere be brought in to study the case.

Several infirmities of rice not supposed to be the work of living enemies have been referred to as diseases.

Three of these which certainly do not have to have a living cause are yellowing, tip-burn, and straight-head. Tip-burn due to excessive mineral nutrition is not rare in the case of young plants on rich land. This was one of the symptoms where I have seen a total failure of the first crop on the site of a sheep corral; freely flowing water without interruption from the time of the first irrigation would probably have saved it. Drying fields thoroughly while the plants are only a few inches tall produces a similar appearance, but strengthens the plants if not carried too far. Yellowing may be due to too close planting, prolonged dark weather, a change to too much or too little water, want of iron or excess of lime (very rarely), or incorrect nitrogen supply; if it is a recurrent or continued field condition, not due to thick stand, the application of animal manures is likely to correct it.

Straight-head means the failure of the heads to turn down as they normally do when the grains grow heavy. Anything which prevents the filling of the grain will result in erect, strict panicles. Because this condition may have any of very numerous causes, it is unsafe to assume that the straight-head reported from different places is alike in anything except appearance. There are even very undesirable strains of rice which hold the panicle erect when well filled.

More specifically, straight-head is the name given to a disease of rice in the Southern United States, the subject of *Farmers' Bulletin* No. 1212 (1921), by Tisdale and Jenkins. Tisdale says he has seen the same condition in Japanese rice at the Biggs station, California, and cites Mirasol as authority for its occurrence in rice following mungoes in the Philippines. Reinking has also reported it in the Orient, and Shaw, commenting on this bulletin, reports disease without an evident parasite in Bihar and Orissa and Kashmir. And it obviously may occur wherever rice is grown. But it is only in Louisiana, Texas, and Arkansas that it is supposed to be dangerous. At maturity, the most striking symptom is that de-

scribed by the name. In addition to this, the panicles do not emerge to the normal distance, or even, in very bad cases, do not come out at all; the flowers abort more or less completely; the leaves are darker than normal, and are erect and stiff in appearance, and their sheaths are tight; and the root system is made up of abnormally numerous, long, coarse roots, with very few branches and hairs. To one watching for the disease, the first symptom is given by the leaves, and the diagnosis can be made positive by examining the roots.

This disease occurs chiefly on new land or land which has raised a dry crop, especially corn or cowpeas. It practically never occurs in rice preceded by rice. It can be prevented by aerating the soil while the plants are growing. If water be withheld for forty days after germination, there is none, or very little of it, on land where the rice suffers very badly if continuous irrigation begins earlier. This long delay in watering gives weeds too great an advantage, if they are present. The recommended practice is therefore to irrigate at the usual time; watch for symptoms; and, if they appear, drain and dry the ground until the surface checks and the plants begin to wither. In experiments, the best yields were obtained if the water was turned on ten days after the seedlings appeared, and left for six weeks before draining off.

The infirmity or appearance of rice called "blast" in English needs mention at this point, although most causes of it will be taken up in discussing the causative organisms. This name is used for a disease caused by a particular fungus; but as the English equivalent of *brusone* (Italy), *falla* (Spain), *imotsi* (Japan), *tiem* or *tim* (Cochin-China), and perhaps *mentek* (Java), it applies to any failure to produce filled heads or to any unexplained failure. In the case of *tiem*, for example, Vincens[1] lists four groups of causes: (1) too little water after transplanting; (2) water allowed to stagnate and become

[1] Vincens, F., "Quelques mesures à prendre contre les maladies du riz appellées 'tiem' en Cochinchine," *Bull. Ag. Inst. Scient. Saigon*, 2. (1920), 90-92.

salty; (3) insect pests; and (4) attack by fungi; and this list may well be incomplete. Two of these causes of the phenomenon are without living agents, and require entirely different measures of prevention from the other two. *Giwa-bo* is the corresponding name in Burma for whatever may ail rice.

The grower of a crop fails too often to appreciate the necessity of accurate understanding of the cause of trouble, before one is competent to prescribe a cure. *Tiem* is no more a disease than is sore throat or fever; it is merely a conspicuous symptom. Of course, one does what one can to overcome it at once and directly; but the finally effective effort is that applied to finding the cause, and the means of overcoming the cause. To illustrate with a plant disease, in preference to fever, which might be more familiar: bud-rot is the most fatal disease of coco-nuts. For years I was after it, and did succeed in stamping out one epidemic by purely empirical methods; but it kept reappearing, where it seemed impossible that its source was other diseased coco-nuts. Trees often die with rotten growing-points without damage (by bud-rot) to neighbouring trees, and many thousands have certainly been destroyed as a protective measure when infectious bud-rot was not present at all. Finally, Reinking identified the causative organism, at least as to the Philippines, and it became clear at once what were the likely sources of infection, how infection could be prevented, and that the decay of the bud from other causes did not endanger the groves.

It is only as the diseases of rice become known with this measure of thoroughness that the most effective and economical means of combating them can be known. The following treatment of diseases and pests is not prepared primarily for plant pathologists and economic entomologists, who have access to the many original papers on the subject, but for rice-growers; it accordingly omits in general such descriptions of the causes of disease as require microscopes for comparison of the living causes, and such terms as only the entomologist

can understand, but includes descriptions of the symptoms complete enough, so far as the information is available and will do this, to let the grower know what living enemy infests his rice, appraise his danger, and be guided accordingly.

For the world's rice industry, the restriction of the damage done by living enemies is probably the second most important means of improvement, the use of better seed having first place. Better economics in the rice business and better cultural treatment probably have third and fourth places; although it is the last of these which is usually first to receive attention when one embarks on the application of modern knowledge to the improvement of any crop industry.

The root-rot of rice in Java, *omo mentek* or simply *mentek*, is an example of a disease which has resisted attempts at understanding it, and the most industrious and persevering attempts at control without an understanding. Although there have been a number of later publications touching the subject, they have added nothing important to the following summary by van der Elst.[1]

In the course of the past year, the investigations of the *omo mentek* have been carried along and brought to a provisional end. These are the conclusions:

The phenomena known under the name of *omo mentek*, etc., are caused by "root-rot," *i.e.* a condition in which the root system, by unfavourable influences of the soil (among which usually the action of parasites is of no account), is incapacitated to supply the plant adequately with water and food materials.

This root-rot is the common rice disease, which is reported in almost all rice lands (*brusone*, *imotsi*, *rust*, *ufra*, etc.), and occurs exclusively on irrigated rice fields. Chiefly infertile paddies with bad ground structure, imperfect drainage, shallow soil, etc., show this disease, which chiefly appears after imperfect aeration, with poor preparation of the soil and the interruption of selection. Also, fertile paddies can indeed suffer from *mentek*, whenever the above factors are unfavourable.

The direct cause is want of oxygen, respectively, the presence of reducing substances, about the roots.

[1] Van der Elst, P., in *Jaarboek van het Departement van Landbouw, etc., in Nederlandsch-Indië*, 1912, p. 66 *et seq.*

The last statement was proved by water cultures, in which oxygen was excluded from the water, and some symptoms of root-rot appeared within two days. When 0·1 g. per litre of ferro-sulphate was added to the solution, completely typical symptoms were produced, even within twenty-four hours. The demonstration that want of oxygen can cause root-rot is conclusive. This has been proved in Italy too.

The preventive treatment recommended follows from this understanding of the cause. Drainage and the thorough aeration of the soil are the best measures, with any possible enrichment of the soil which does not involve the addition of reducing substances, and any practicable rotation of crops introducing one which favours aeration. The basic difficulty is that the regions most afflicted with *mentek* have soil which dries exceedingly hard, and is little suited to other crops than rice. Steady attention and effort during the decade since the above report was written have been practically without effect. Van Hall [1] reports great damage in 1920, especially on alluvial soils, even the young seedlings being attacked, probably because submerged. And in the corresponding report for 1921, 12 per cent of the whole rice area in Java and Madura is reported a total loss, besides the damage, short of destruction, on other lands! This unprecedented damage is ascribed to an exceptionally rainy East monsoon in 1920.

The Dutch have worked too long and too effectively with the enemies of Javanese crops to leave justification for anything more than tentative suggestions by an outsider. However, van der Elst's identification of *mentek* with *brusone*, *imotsi*, *rust*, and *ufra* leaves the case very open. The Japanese know that *imotsi* is usually caused by fungi, and fungi are a demonstrated possible cause of *brusone*; if there is a *rust* of rice, fungi cause it; and *ufra* is the symptom of attack by a worm. The local and epidemic character of *mentek*—unknown

[1] Van Hall, C. J. J., "Ziekten en plagen der Cultuurgewassen in Nederlandsch-Indië in 1920," *Meded. van het Inst. voor Plantenziekten*, Batavia, 1921.

where rice is deeply and constantly irrigated in Bengal, Burma, Siam, Cochin-China, and the Philippines, and even in parts of Java—strongly suggests a living, multiplying enemy. What this may be, if any such thing exists and is responsible for any part of the damage—whether a worm, as was for a time thought proven, or bacteria (which, as a cause of root-rot, have been blamed for *brusone*), or a fungus (a *Pythium* from rice roots has caused a rot of cane roots in Hawaii)—may, of course, not be guessed.

If there is ever serious damage to growing rice by bacteria, it has not been established. Voglino is said by Farneti to have reported them in 1897 and 1903 as causing root-rot in Italy. They are one of the causes of spotted grain, following punctures by bugs, and they assist in the decay of damp stored rice. Striped leaves in the Philippines are ascribed to them by Reinking, but this disease has never had careful study and is not considered dangerous.

The damage done by (A) fungi and (B) worms (diseases), and (C) insects and (D) other animals (pests), will now be taken up in the order of the causative organisms.

A.—FUNGUS DISEASES

Fungi are colourless (that is, not green like other plants) plants, the vegetative body (or mycelium) of which is made up of threads called hyphae. Because they have not the green substance common to other plants, they must take their food from other plants or animals. If they attack living plants they are called parasites; if they get their food from the dead remains of other things they are saprophytes: many fungi can do either. Typically they reproduce by means of spores, and are classified according to the manner in which the spores are produced; but the degeneration characteristic of parasites has gone so far that some of them rarely or never produce spores. Another method of reproduction is by the formation of compact little

balls or masses of hyphae, able to dry out for a time and resist decay, and grow again when the conditions are favourable. Such masses are called sclerotia (single, sclerotium).

The Sclerotium Diseases.—A fungus forming sclerotia, with hyphae branching at right angles and divided by cross-walls, and not producing spores, is classified in the form-genus *Sclerotium.* These fungi do more or less serious damage to rice in many countries. In the Philippines a sclerotial disease has been reported several times, and carefully studied by Pereira.[1] Besides rice, it attacks plants, at least seedlings, of many other kinds. Inoculations with the fungus from rice were fatal to seedlings of soy beans, cowpeas, garden peas, Goa beans, peanut, pepper (presumably *Capsicum*), papaya, sesame, and squash; and the same fungus has been found in carrots and the leaf-sheath of sugar cane.

The injury to rice is most serious in the seedling stage. The seed-beds of the College of Agriculture, in June 1920, contained 126 varieties, of which 19 were very badly attacked, and only 25 were free. The fungus spreads over the ground, and grows up on and in the young plants. Many plants are killed and many more injured and stunted. The sclerotia are from $\frac{3}{4}$ to $1\frac{1}{6}$ mm. (say, $\frac{1}{20}$ to $\frac{1}{30}$ of an inch) in diameter, roughly spherical, and dark brown on the outside. They are formed on the outside of the plants, or in the pith cavity, or in the bundles—wherever there is room. They survive, while the host plant dies and breaks down. They can live in dry soil for five or six months, and for twelve or thirteen months in moist soil.

Older plants in the field are in general less subject to attack. Good spacing and clean weeding, letting the air circulate freely through the field, are therefore the means of safeguarding upland rice. Irrigated lowland rice is in no danger, if watched, as flooding always stops the growth of the fungus.

[1] Pereira, E. de B., "Sclerotial Disease of Rice," *Phil. Agriculturist,* 19. (1922), 331.

In Java, as in the Philippines, seed-beds are chief points of sclerotium attack; the fungus is presumably the same.

Apparently the same fungus studied by Pereira, as checked by cultures taken from the Philippines to the United States, is known also in Louisiana,[1] where it is identified as *S. Rolfsii*, Sacc. There too its attack is chiefly on the young seedlings; and emphasis is placed on the killing of many of these before they emerge from the soil—an injury which does not strike the eye and is easily ignored. Seedlings killed after they grow into sight die slowly, and are therefore dark in colour, as compared, for example, with those killed quickly by root maggots. They also become hosts of various saprophytes and secondary parasites, including *Alternaria* and *Helminthosporium*. The brown sclerotia are found on the roots and the bases of the stems. Other local hosts of the fungus are soy beans, wheat, and tall oat grass. Cultures from wheat attack rice as vigorously as those from rice itself, but those from other hosts are less virulent toward rice. As in the Philippines, water has proven the best means of controlling this disease.

Sclerotium oryzae, Catt., first described in Italy in 1879, and said to be destructive in Lombardy and Novara, is a more widely known fungus, with smaller, black sclerotia, distinguishable in its effects by its usually attacking older plants. Tisdale ascribes its spread in the field in Louisiana to sclerotia floating on the irrigation water. Coming in contact with plants, they attack the leaf-sheaths first, and then work inward, destroying the tissues of the stem and producing a more or less complete stem rot. According to the intensity of the attack on the individual plant, the result may be to cause imperfect filling of the grain, or more or less complete sterility. Japanese varieties were found less susceptible than the more popular long-grained ones in Louisiana, *early prolific* being the most so of all. These

[1] Tisdale, W. H., "Two Sclerotium Diseases of Rice," *Journ. Agric. Research*, 21. (1921), 649.

differences indicate the practicability of selection of resistant strains, if the damage is serious enough to demand such measures.

Shaw[1] and Butler have published accounts of sclerotial diseases in India, the fungus being identified in part as *S. oryzae*. At Pusa the injury appears late in the season, which is characteristic of this species; but emphasis is placed on the formation of fresh green shoots from the base of the plant as the most conspicuous symptom, which is not reported in Italy or Japan, and does not occur in Louisiana. *S. glumale*, Ces., is also reported in Burma.

In a very comprehensive account of the fungi on rice in Japan, Miyake[2] reports *S. oryzae* as widespread and well known there, making its annual appearance in August and September. It can destroy all of the internal tissues, so that the culms fall over. *S. irregulare*, Miyake, on the sheaths, is commoner in Japan, where rice straw has been worked into the fields. It is distinguished from *S. oryzae* by the larger sclerotia, and from *S. glumale* by their black interior. It forms large ellipsoid spots, whitish with brown margins. It too attacks late in the season. Still another *Sclerotium*, not specifically identified, causes a real disease in Japan. Miyake is said to have made *S. oryzae* produce spores, by which it was shown to belong in the genus *Hypochnus*. Its appearance recently in Louisiana and Arkansas may be due to importation from Japan.

S. irregulare is reported also in Bengal, and *S. glumale* in Borneo. And Reinking reports a sclerotial stem rot in Southern China. The same author ascribes a stem rot in the Philippines to a fungus of the genus *Rhizoctonia*.

Fusarium.—An unidentified fungus, believed to belong to this genus, is said by Miyake to cause material damage in Japan. A fungus in the same genus is reported by Bryce in 1920 as destructive in seed-beds

[1] Shaw, F. F., "A Sclerotial Disease of Rice," *Mem. Dept. Ag. India*, Bot. Series 6 (1913), 11-23.

[2] Miyake, I., "Studien über die Pilze der Reispflanze in Japan," *Journ. Coll. Agric.*, Tokyo, 2. (1910), 237.

in Ceylon, but harmless after the seedlings are four inches tall. *Macan piña,* introduced from Manila, and *hatiel* are the most susceptible varieties. *Fusarium roseum,* Lk., is a very widespread pink mould, usually known as a saprophyte, and said to be the conidial form of *Gibberella Saubinetii,* Sacc. Novelli states that it attacks rice in many places in Italy, and is especially injurious to awnless varieties. To keep it out, he recommends the use of clean, mechanically recleaned and sterilized seed.

Helminthosporium.—Fungi of this genus have been found parasitic on rice in Italy, Java, Ceylon, India, Indo-China, the Philippines, and Japan, and on dead rice in China and Louisiana. The four described species, *H. oryzae,* v. Breda de Haan, *H. macrocarpum,* Grev., *H. sigmoideum,* Cav., and *H. maculans,* Catt., differ only microscopically. They appear first as seedling blights, killing a proportion of the seedlings when they are only about an inch tall, weakening others, and continuing to attack plants up to maturity. Plants not killed may remain completely sterile. The symptoms appear first on the leaves, and spread rapidly to all aerial parts of the plant.[1] Small brown spots, the size of a pin-head, more distinct on the lower than on the upper surface, appear within a day or two after artificial infection. These enlarge, darken in the middle, and have a yellowish border. Finally, the middle turns grey as the spots become irregular and coalesce, leaving dead, velvety-looking areas. Late in the season the fungus attacks the basal node of the rachis, producing a blast, which can be distinguished from that caused by *Piricularia* by the lighter colour and velvety appearance of the point attacked and the wider curve of the infected head.

Due to the rapidity of infection and development, this fungus can spread readily through a growing field. It lives over from season to season by means of spores

[1] Nisikado, Y., and Miyake, C., "Treatment of Rice Seeds for Helminthosporiose," *Ber. Ohara Inst. f. landw. Forsch.,* 1. (1920), 543; "Studies on the Helminthosporiose of the Rice Plant," *ibid.* 2. (1922), 133.

borne on the seed and by spores in the soil; the former proved by the presence of 12·5 per cent of infected seedlings on sterilized soil, and the latter by the presence of infected seedlings from sterilized seed. Sterilization of the soil is impracticable except sometimes in the seed-beds, and if the infestation is serious enough it would be expedient, where possible, to plant a clean-cultivated crop immune to the fungus. Nisikado and Miyake made a very careful study of the sterilization of seed, the results of which, at least as far as the power of resistance of the rice seed is concerned, are equally applicable to disinfection for all diseases. Soaking dry rice in water for fifteen minutes at a temperature of 55° C. does not injure it, but may increase the per cent of germination. Rice previously soaked for twenty-four hours at a temperature of 19·5° to 23° has its germination per cent lowered slightly by immersion for ten minutes, but not by five minutes at this temperature, nor by ten minutes at 54°. The spores of *Helminthosporium* are killed by ten minutes in water at a temperature of 50° to 52°, and the germinated spores by the same exposure to 48° to 50°. This leaves a broad enough margin for easy and safe disinfection with warm water. The treatment recommended is to soak the seed for twenty-four hours at the ordinary temperature of the sowing season, and then for ten minutes at 51° or five minutes at 54°. If the use of a chemical disinfectant be preferred, ten minutes in a 2 per cent solution of blue vitriol is effective and safe.

The same *Helminthosporiums* attacking rice have everywhere been found to be able to live on some other grasses. In Japan, fifty other grasses, including maize and sorghum and barn-yard grass and many other common neighbours of rice, are subject to infection by *H. oryzae*. Beside the species already mentioned, Shaw reports that at Pusa *H. teres*, Sacc., from barley and *H. turcicum* from maize and sorghum are able to infect rice. It follows from these facts that, where these fungi are doing damage to rice, disinfection of the rice seed can be trusted to provide only a limited measure of

freedom by itself. To provide greater freedom, barnyard grass and other alternative hosts must also be eradicated from the fields and neighbourhood as thoroughly as possible; such care is very good for the rice directly, and will cut down the danger of damage by other pests and diseases as well.

An unidentified *Helminthosporium* [1] was very abundant in the exceptionally rainy and cloudy season of 1918–19 in the deltas of the Godaveri and Kistna rivers. It finally attacked the nodes and glumes, and caused some shrivelling of the grain, but is not regarded as dangerous in ordinary seasons.

Piricularia oryzae, Bri. et Cav.—This fungus is found in every Oriental rice country, and has accompanied rice around the world. Its effects are known in English as blast, less commonly as blight and rotten-neck. It is the most frequent cause of *imotsi* in Japan, and is a demonstrated possible cause of *brusone* in Italy, although not generally regarded as the chief cause of it. The following description is taken chiefly from a study of it in Louisiana by Fulton.[2] It is considered identical with *P. grisea*, living on crab-grass (*Panicum sanguinale*).

When blast attacks young plants, the first observable symptom is the appearance of brown spots on the leaves. These are ashy-grey in the centre, and enlarge and coalesce, until the whole leaves are involved and turn brown and dry up. Where rice is grown during a single well-defined season, the disease is not likely to make itself conspicuous while the rice is young. When it appears later, attacking older plants, leaf-spotting may appear, but does not spread and destroy the plants in this way. The commoner points of evident attack and destruction are where the leaf-blade joins the sheath, and at the bases of the sheaths, that is just above the nodes. At the latter points, small, pale, watery spots appear. These enlarge, darken, spread inward and upward,

[1] Sunderaraman, S., "Helminthosporium Disease of Rice," *Ag. Res. Inst. Pusa Bull.* No. 128, 1922.

[2] Fulton, H. R., "Diseases affecting Rice in Louisiana," *La. Agric. Exp. Stat. Bull.* No. 105, 1908.

and finally kill the tissues completely, leaving small cracks where the dead tissues contract. The upper nodal areas are most subject to attack, especially the "neck," "where the stem comes to be the axis of the head."

The results are various, depending upon how severely the individual plants are affected. A late attack may merely weaken the plant, causing the grain to fill imperfectly, cup light, and give a poor milled product; or it is very likely to be light enough to blow over in the threshing, cutting down the crop very materially. In other cases, the heads fill, and the weakened neck cannot hold them, so that they break down and fall off, before or during the binding. Or the grain may not fill at all, in which case the whitish empty heads stand up, as in straight head or following attack by a borer.

The fungus spreads rapidly from plant to plant, by means of spores set free on the outside of the host. These are minute three-celled oval structures, easily scattered by the wind, and able to germinate at once. In Fulton's experiments on outdoor plots, drops of water containing spores placed on sound plants produced signs of disease on many plants within five days, and on every plant within nineteen days, regardless of the age of the plant. This testifies to a very high virulence of the disease, under conditions favourable to it. In experience, in the more seriously affected districts of Louisiana, the damage is said to run from 5 to 25 per cent.

As to preventive measures, the most promising should be breaking the life cycle of the fungus between crops. This is largely accomplished naturally in temperate countries, as shown by the comparative freedom of young fields. The practice of burning the stubble may help to free the fields. Reinking has suggested an alternation of crops, to clear Chinese fields of infection. Complete eradication of this fungus should be possible if the means by which it survives the winter were known. It may be necessary to eradicate crab-grass, and eventually still other hosts. When the conditions are thoroughly understood, prevention of the appear-

ance of the disease will probably be found possible and practicable.

Very thrifty and productive fields are said to be less susceptible to attack; but too much respect should not be given to this statement, regarding any disease or pest, unless it is supported by very careful observation. New fields (that is, rice on new land) seem to be especially subject to attack. Rice on land which has been rested is reported to be particularly susceptible in South Carolina, where land remains wet while not planted, but not in Louisiana, where it rests dry. In Italy, poor aëration of the soil has been said to be conducive to attack by blast, but the confusion of ailments under the name of *brusone* prevents agreement on this point and leaves it doubtful. Liming has seemed to lessen the injury in South Carolina, but in Louisiana ample experiments have shown no relation between blast and any fertilizers whatever.

In South Carolina, spraying with Bordeaux mixture while the rice is in the boot (barrel) has been found to prevent serious damage, and this treatment has been recommended in Italy. However, the spraying of rice fields in general, for the control of this or any other disease or pest, may as well be regarded as impracticable.[1]

No variety of rice is known to be immune to blast. *Bertone* was almost or quite immune to *brusone* when first introduced into Italy, but has lost this freedom, either by loss of resistance on the part of the rice, or development of the power of infection by the fungi; and a series of more recently introduced varieties have a similar history in Italy and Spain. In Louisiana, red rice is regarded as most susceptible, *Kiushu* next, and *Honduras* least. Because of the increasing prevalence of the disease as each season advances, early varieties are relatively little exposed, and the greater observed damage to the Japanese variety may have been due entirely to its lateness.

[1] Tanaka (in *Mycologia*, 14. (1922), 81) states spraying has been employed effectively in Japan for the control of *Helminthosporium oryzae*.

In the Southern states, no relation has been established between the humidity of the air and the spread of blast, but it can hardly be doubted that such dryness of weather as California rice enjoys is likely to decrease the danger of serious damage when blast appears there. The power to spread most rapidly in humid air is characteristic of fungus diseases in general, as illustrated by the *Helminthosporium* already mentioned in the Godaveri delta. In any given place, the weather is uncontrollable, but the humidity about rice plants, where fungus spores must germinate to produce disease, can be limited by the appropriate use of water, open planting, and freedom from weeds.

American workers have been disposed to identify *brusone* with the blast caused by *Piricularia*, and it is agreed that the *falla* in Spain is identical with *brusone*. Shaw,[1] at equally long range, recalls that Brizi produced *brusone* in cultures by lack of aeration, and cured it by introducing an alga which increased the supply of oxygen. There is no reasonable doubt that *brusone* can be caused by *Piricularia* and various other fungi, and by lack of aeration of the soil; and it is not at all unlikely that there are still other causes. An interesting posthumous note by Farneti[2] reviews the history of its study. As early as 1871, Garavaglio ascribed it to *Pleospora oryzae*, Catt., which is *Mycosphaerella oryzae*, Sacc., a fungus common in Italy and present in Japan. It appears usually in July and August, attacks the leaves, which turn pale and die, and stunts the grain. Several other fungi were brought under suspicion by Cattaneo, but not shown to be primary causes. In 1892, Briosi and Cavara found *Piricularia* the commonest parasite present, but neither they nor a special commission appointed by the Ministry of Agriculture found *brusone* dependent upon it. Voglino's discovery of bacteria in the roots of diseased rice, and Brizi's produc-

[1] Shaw, F. J. F., "A Diseased Condition of Rice," *Ag. Journ. India*, 17. (1922), 152.

[2] Farneti, R., "Sopra il 'brusone' del riso," *Atti Ist. Botan. dell' Univ. di Pavia*, ii. 18. (1921), 109; *Rev. Appl. Mycol.*, 1. (1922), 343.

tion of *brusone* by deprivation of oxygen have already been mentioned. In the meantime, Ferraris proved that *Piricularia* could produce its symptoms, Metcalf in America produced the same symptoms by inoculation with this fungus, and Miyabi, Hori, and Kawakami in Japan found that both *Piricularia* and *Helminthosporium* could produce practically the same results. Farneti himself furnished cultural proof that fungi could cause *brusone,* and came to the conclusion that the "fungi associated with it were in great part only different forms of one highly polymorphous species which included *Piricularia oryzae, P. grisea, Helminthosporium oryzae, H. macrocarpum, H. sigmoideum, Cladosporium* sp. and *Hormodendron* sp."

It is still the more general belief in Italy and Spain that inorganic causes are chiefly responsible for the disease. But in sharp contrast to this expressed belief, their authorities agree on the efficacy of disinfecting the seed.

Phyllosticta.—Four species ascribed to this genus have been described as rice parasites. *P. oryzae* (Cke. and Mass. as Phoma), Miyake, was first described on rice straw from Calcutta. In Japan it attacks the sheath, forming irregular dark blotches. It may destroy the sheath and thereby injure the blade. *P. Miurai,* Miyake, was described in Japan, without note as to its effect. Reinking found it in China, but regarded it as a saprophyte. Baker reports that in the Philippines it forms small spots on the leaves, and is sometimes injurious enough to cause a large part of the leaves to turn whitish and die. *P. glumarum* (Ell. and Tr.), Sacc., is known from Ceylon to Japan, if Miyake's suspicion that *Melanomma glumarum,* Miyake, is the same fungus. In China, Japan, Formosa, and the Philippines, the kernels within the glumes turned brown by it are worthless. *P. japonica,* Miyake, known only in Japan, attacks both leaves and glumes, and destroys the leaf completely. When it attacks young glumes, no kernels are formed. If the attack occurs later, the result is spotted or discoloured kernels of little value.

Other Leaf and Glume Fungi.—Besides the *Mycosphaerella* already mentioned in connection with *brusone*, there are *M. Hondai*, Miyake, on leaves in Korea, and *M. shiraiana*, Miyake, on leaves and sometimes on glumes in Japan, the latter believed to do much damage. *Phaeosphaeria oryzae*, Miyake, on leaves and glumes, is common in Japan, and is the cause of the "white disease," *Shiro-hagare-byō*. The infected leaf gradually whitens, without any formation of regular spots, until no green part is left. On the hull, it causes darkening at first, then whiteness; the kernel develops imperfectly if at all, and turns brown. This fungus is very destructive in Western Japan. The same name, *omo putih*, is given in Java to the work of an insect. *Metasphaeria albescens*, v. Thüm., on leaves and glumes, was not considered dangerous where first found, at Aquileia, on the "Austrian" coast, but is common and destructive in Japan. It begins by forming fine, black-brown spots, which enlarge and turn yellowish brown and finally grey, and may destroy the foliage completely. *Chaetophoma oryzae*, Cav., in Italy and *C. glumarum*, Miyake, in Japan produce pale glumes overlaid by the black mycelium, and interfere materially with the formation of the kernels. *Pyrenochaeta oryzae*, Shirai, on leaves and glumes in Japan, attacks on low, heavy soil, about the end of July. The attacked leaf turns pale at the tip at first, but finally brownish all over. As such plants are easily pulled up, the damage seems to reach to the roots. The panicle fills very incompletely.

Coniothyrium japonicum, Miyake, found at Kagoshima, causes an infection of the leaf, which spreads from the tip and edges, the colour turning through brown to whitish. *C. oryzae*, Cav., in Italy, *C. brevisporum*, Miyake, and *C. anomale*, Miyake, in Japan, differ only microscopically, and in that the last does more localized damage to the leaves. *Sphaeronema oryzae*, Miyake, in Japan, turns the glumes whitish. *Hendersonia oryzae*, Miyake, in Japan, on leaves and glumes,

makes brown spots on the latter, and injures the kernels seriously. *Septoria longispora*, Miyake, in Japan, turns the glumes grey and prevents the formation of kernels. *S. curvula*, Miyake, is a weak parasite on leaves in Japan, infectious where overflows have already weakened the rice. *Cladosporium oryzae*, Miyake, was found on the leaves of a Siamese rice tested in Japan. *Epicoccum neglectum*, Desm., is common on the tips of young leaves and on glumes in Italy and Japan. *E. hyalopes*, Miyake, occurs on glumes in Japan. *Oospora oryzetorum*, Sacc., found in the Philippines by Baker, causes a whitish bloom near the time of maturity, which spreads through the panicles, and is particularly conspicuous in reddish and brownish varieties. The affected rice is very largely blasted. A species of *Napicladium* is reported by Rutgers as the cause of leaf spots in Java. Snowden reports rice in Uganda attacked by *Helminthosporium* and an unidentified *Leptosphaeria*; the latter covers the leaves with yellowish-brown spots, and gives the appearance of scorching by fire. In Mesopotamia, a "burnt ear disease," probably the work of a fungus, was prevalent in 1919.

Sclerospora macrospora, Sacc., besets the panicles in Italy, causing considerable injury. *Puccinia oryzae* was reported in Spain in 1914 and in Italy the following year. In the former country, it was credited with destroying 7·5 per cent of the crop of the right delta of the Ebro.[1] Most elaborate preventive measures were advised, including disinfection of the soil, and the sane observation that joint action covering the whole infected district was demanded, if expensive measures on any part of the area were to be worth while.

Green Smut, Ustilaginoidea virens (Cke.), Tak.—This fungus is perhaps as widespread as *Piricularia*, but is less destructive. It attacks single kernels, which it destroys utterly, substituting for them much larger sclerotial masses of its own. Each of these is big enough

[1] Florensa y Condal, J., *La enfermedad del arroz* (*Puccinia oryzae*), Tarragona, 1914, 32 pp.

to spread the hull wide open, so that the greenish fungus ball, a quarter of an inch or more in diameter, is very conspicuous. The colour is due to the spores, which are borne all over the surface. These balls are big enough to be gotten rid of mechanically in threshing, so that the milled product is not damaged.

Baker reports that this fungus is always present in Philippine rice, and sometimes does material damage. It has long been known in Japan, but is not considered very dangerous. In Louisiana, the loss of crop when it is most abundant is only a fraction of 1 per cent. And in Sumatra, the growers, instead of fearing it, are said to regard its appearance as an indication of a crop fine in both quantity and quality.

Black Smut, Tilletia horrida, Tak.—This is still another ubiquitous parasite, never known to be very prevalent, but more serious than the preceding, because it may materially lower the quality of the milled rice. It seems probable, but is not positively known, that this smut spreads by infection of flowers by spores from the diseased grains, and that the seed produced by an infected flower will in turn produce a plant on which some of the grains will be smutty. Thus the infection occurring in any one season has no evident effect until near the maturity of the next crop.

The kernel attacked by this fungus is finally replaced by the fungus, with or without enlargement, but without enough to make it mechanically separable. When the fungus is thoroughly ripe, it is made up almost wholly of black spores, which are freed by the rupture of the thin membrane which has enclosed it. The spores are numerous enough, if infection is severe, to discolour the sound rice when it is milled. In South Carolina, *Tilletia* was once abundant enough to produce several per cent of smutty grains from the worst fields, but was later stamped out. In Louisiana, it has attacked red rice and *Honduras* rice chiefly, but never become a serious pest. In Japan, where it was first described, it is not prevalent enough to be considered a serious disease.

In Java,[1] it has not been known long, and seems to be local. It is reported also in India, China, and elsewhere.

If *T. horrida* has the life history presumed above, it may or may not be possible to get rid of it by disinfection of seed. The sure preventive is the use of seed from a locality where it does not occur.

All of the many other fungus parasites of rice can be guarded against together, by such measures as have already been described — disinfection of seed, by hot water or by the use of chemicals; such cultural treatment as will restrict the presence of weeds, likely to be alternative hosts, in the fields and as far as may be practicable in the neighbourhood; avoidance of too close planting, such as would facilitate the spread from plant to plant and increase the humidity about the foliage; and, as an extreme measure, rarely to be thought of, the temporary use of the ground for some other crop.

Grain-spotting Fungi.—A number of fungi which do not cause disease still damage rice, while it is growing, or while it is still in the growers' hands. These are saprophytes rather than parasites, and are as a rule the prevalent saprophytes of the different countries. Those which injure the kernels in the field reach them as a result of mechanical injury, usually by means of punctures made by bugs. If the insect does not directly destroy the kernel, it may do so indirectly by the infection it causes; or the kernel may merely be spotted or shrivelled, impairing the quality of the milled rice. Prevention of such damage can only be by getting rid of the insects.

The various bacterial and fungus saprophytes which attack and eventually injure or spoil damp rice in storage likewise need no listing. The preventive measures are obviously such as keep the rice dry. Rice imperfectly cured or not cured before warehousing may set free enough moisture by "sweating" in the sack to

[1] Rutgers, A. A. L., "Stuifbrand bij rijst," *Meded. van het Lab. voor Plantenziekten*, No. 11, 1914.

expose itself to this kind of damage, without any external source of water.

"Yellow kernel," caused by *Protoascus colorans*,[1] is a discoloration of rice observed in Java during the curing after harvest. It is caused by a fungus which grows in the grain and gives out a yellowish-brown pigment, penetrating the entire grain, if it is killed slowly by the drying of the grain. If killed quickly, it does not excrete the pigment.

Miscellaneous Saprophytes.—Besides the fungi known to be parasites, there are a large number of others known on the dead rice plant, some of which are probably able to attack living rice as well. Miyake describes fourteen of these, in addition to the many species mentioned above; Reinking names yet ten others found in the Philippines; and there are still a number known in Italy and elsewhere. In a number of instances, fungi stated positively not to be parasitic in some countries have been found to do material injury in others. When it is considered that the fungus enemies of rice in most lands have not yet received study comparable to that given them in Japan, it will easily be anticipated that the large number named in the preceding pages are far from being all that exist.

Baker has estimated that fungus diseases, collectively, may reduce the Philippine crop by 5 per cent. This would probably be a high estimate for the whole world; otherwise, the loss they cause approaches two hundred million dollars.

B.—DISEASE CAUSED BY WORMS

The nematode worms which live as plant parasites and cause diseases usually attack the roots, and almost invariably live inside the plants they attack. Such a worm, *Tylenchus oryzae*, was described in 1902 by van Breda de Haan, and believed at the time to cause root rot. It is 1·5 mm. long and $\frac{1}{35}$th as thick, and lives in

[1] *Jaarboek van het Dept. van Landbouw*, etc., 1913, p. 137.

the roots of rice. Later studies (see *Jaarboek*, 1909, p. viii.) showed the worm to be present in healthy plants, and failed to produce the disease by inoculation with it.

Another species, *Tylenchus angustus*,[1] attacks the shoot of rice, and does very great damage, but never enters the tissues of the host. This species is described as hardly 1 mm. long and $\frac{1}{50}$th as thick. A spear is projected from the mouth to puncture the rice plant, and then withdrawn into the pharynx. The eggs are large and very numerous. The worm cannot develop away from the rice plant. When it dries out, as it does to pass over the dry season, it coils into a perfect disc, with the head in the centre. In this condition, many remain alive for seven months, and a few after fifteen months. It survives for a short time in water, away from the rice plant. It is the specific and sole cause of the disease called *ufra*.

The worm is not known to have any other host than rice. It attacks only young parts of this, the leaf sheath, the zones of the stem just above the upper nodes, the young peduncle and panicle, and the young blades while they are still rolled up in the bud. It punctures these by means of its spear, hardly 0·01 mm. long, incapable of puncturing an old epidermal wall or reaching any tissue deeper than the epidermis. It sucks the juices from the cells it punctures, and this seems to be the limit of its direct damage. Bacteria and fungi sometimes use its lesions to enter the plant; but chiefly, the seriousness of the disease is due to the little bit of sucking done from the young structures by each of the vast number of the worms. On any plant, they typically reach their maximum number just as the panicle is ready to be attacked; then "the strain becomes more than the plant can meet." They rarely kill rice, but far too commonly make it sterile.

The area infected, without definite knowledge of the

[1] Butler, E. J., "Diseases of Rice," *Agric. Res. Inst. Pusa Bull.* No. 34, 1913; "The Rice Worm (*Tylenchus angustus*) and its Control," *Mem. Dept. Ag. India*, Bot. Series, 10. (1919), 1-37.

limits at some points, was estimated in 1916 as at least six million acres, out of the twenty-one million in Bengal. Another six million acres in Bengal and two million in Sylhet were apparently open to invasion. On all the bottom lands and lower terraces of the infected area there was damage—total, or leaving only forage to be cut, or partial. There was no basis for an estimate of the total damage; the scattered estimates were a lakh or two of rupees here, a thousand acres there, but Butler says that in Indian agriculture only epidemic rust in the dry cereals can do comparable mischief. And *ufra* not only attacks a crop demanding a far greater effort in its preparation and care than does a dry grain, and occupying more than two-thirds of the whole cultivated area of Bengal, but its ravage is worst in exactly those spots, the lowest areas, where no other crop, not even jute, can be planted in the place of rice.

While able to live for a time and move very actively in water, *Tylenchus* normally attacks the rice plant above its surface. As it does not feed, at any rate to any extent, under water, and does not copulate there, and the eggs are deposited and hatch in the air, and it is only by virtue of immense numbers that the worm is destructive, the key to an understanding of the possibility of restricting its evil activity is found in the fact that it is only in approximately saturated air that it can move about and find a place to feed and copulate, and for the eggs to hatch, and only in such air that the young worms can grow from moult to moult. During March and April, the height of the dry season, the disease is unknown. It is apparently dormant in May, although on low, wet ground there is probably a spreading of the worms, the effects of which appear in June. And in January and February it is found only on fresh young shoots from the old butts of harvested rice. As a disease, *ufra* is confined to the months from June to December.

According to their seasons, the Bengal rices are classified as *boro* or spring varieties, with an extreme season from November to May; *aus* or autumn varieties,

from March to September; and *aman* or winter varieties, from March to December. *Boro* rice is rarely if ever attacked, having its growing season while the worms are dormant, besides being transplanted. Transplanted rice of the other classes is rarely and not seriously attacked. In part, this is because transplanting is most general on the higher ground. Such ground is dry for a considerable part of the year and is well cultivated; and the stubble is mostly short, while the worms live in the higher parts of the plant. Even on lower paddies, transplanting is done on to land better cultivated than for broadcast sowing, and dry for some time. Also, it is not unusual for the new season's water to be standing for a time on such paddies before the rice is transplanted; and any worms which survive the cultivation and drying are likely to die soon in water containing no growing rice. It is on the bottom lands and the lower terraces that broadcasting is the general practice, and there that *ufra* is generally destructive.

The season and method of culture spare some varieties from attack, but there is probably no natural immunity, even partial. Early rices suffer comparatively little, because they are mature before the worms become most numerous. For this reason, Hector has advocated the more extensive planting of such varieties. Not much can be accomplished by raising the level of the paddies, nor by increasing the transplanted area; for the growers try constantly to raise the level for other reasons, and already transplant except where natural conditions make it impracticable. In some places the area in *boro* can be increased, leaving the land idle during the season for the *aman* crop; but this is possible only where water can be provided for the *boro*. If this involves considerable work, in the construction of new irrigating canals, the value of the canals as ways of communication in a roadless land offers an added incentive. Also, the *boro* crop is worth more than the deep-water broadcasted *aman*, regardless of the damage to the latter by disease.

Except on limited areas so swampy that the stubble cannot be burnt nor the land well cultivated (to which areas the preceding suggestion applies particularly), the most effective method of handling *ufra* has proved to be by the very complete removal of the stubble, mechanically or by burning it on the land, followed by early, thorough, and repeated cultivation. *Repeated* evidently means something here; for Butler mentions one set of sixty-four plots (46·5 acres in all) which were ploughed ten times, and another of twelve plots (nearly 11 acres) which were ploughed and harrowed fifteen to eighteen times. None of the latter showed a trace of *ufra*, and only nine of the former were slightly affected. In other places, burning, followed by less remarkable cultivation, gave very satisfactory results. It appears, after years of study and experiment, that practicable efforts will break the annual cycle of the worm sufficiently to keep within tolerable bounds the damage it can do.

Ufra seems to have made its first appearance near the coast, twenty or thirty years ago. The date may be considered uncertain, but the disease is at any rate not ancient; for rice is ancient in this region, and the spread of the disease can be traced positively in recent years. The question of its origin is an interesting one. Appearing near the coast, it was probably imported. But where else is it, then? In a drier land than the Gangetic delta, or where lowland rice is all transplanted, it might long escape detection by doing little damage, or be overlooked as a factor in such a disease as *tiem*, where all diseases are known by the general symptoms, but the causes are ignored. To date, the only other report of it is by Jack, in the Malay States, where it attacks roots and young shoots, but does not appear to be exceedingly destructive. Wherever else it may be, it is in Bengal; and, while seed infection is not a chief means of spreading the disease, it is a possible one. Paddy rice from Bengal, whether for seed or intended for milling, should be admitted to other rice-growing lands only after complete disinfection.

C.—INSECT PESTS

While at least three, and probably a larger number, of fungus parasites have managed to accompany rice across the ocean, no insect pest of growing rice is known to have been so fortunate. The difference is easily accounted for by their means of dispersal, the insect having no stage in which it can naturally be carried with the rice seed, without being seen, and remain alive for a long time. The insects can, however, fly instead of having to depend upon chance for their distribution; and several of them are found almost or quite all over the home land of rice, where 97 per cent of the world's crop is raised. The total damage done by insects is materially greater than that done by fungi.

The largest list of the insects injurious to rice to which I have had access is that in Pierce's *A Manual of Dangerous Insects (likely to be introduced)*, issued by the U.S. Department of Agriculture in 1917. I have added many to this list, without yet mentioning all which have been identified. But the following exposition is believed to include all which have been reported as doing any serious mischief.

Orthoptera. — Locusts and grasshoppers are not specific pests of rice, but may in the aggregate do as much damage as any of the plant's particular parasites; and the economic damage wrought by their attacks on rice is probably greater than by that done to any other crop. Species mentioned in connection with damage to rice are *Oxya velox*, Fabr., and *O. intricata*, Stal, widespread in the warm Orient; *Hieroglyphus banian*, Fabr., in India; *Phaneroptera furcifera*, Stal, in the Philippines; *Racilia okinawensis*, Mats., in Formosa; and *Xiphidium varipenna* in Hawaii. Some injury by the eating of part of the foliage is common. Total destruction, by swarms of the migratory locusts, is comparatively rare, and most likely to occur in lands not yet very densely populated, as Minahasa and Mindanao. The *Hieroglyphus* is said

to do more damage by eating through the upper part of the stem than by eating the leaves.

While enormous numbers of the adult locusts are sometimes caught (and eaten), this does not operate appreciably to save the crops. Single fields are sometimes saved by keeping the swarms on the wing. Really effective work is sometimes done by ploughing up the areas where the eggs have been deposited. And swarms are not rarely reduced to practical harmlessness by driving them into pits or ditches and killing them while they are still in the hopper stage.

Anything like freedom from danger from migratory locusts, in lands subject to them, is to be looked for only by the elimination of unused grass lands, either by bringing them into cultivation or by their afforestation. One of the chief objections of Government to *caingin* culture (see p. 220) is that it results in an increase in the area where locusts can breed. A large part of the grass areas of the Orient are man-made, and tend to return to forest in the absence of fire. Densely populated lands tend to become free from locusts by the extension of cultivation.

Mole crickets (*Gryllotalpidae*) are listed among the minor pests of many lands. As the damage they do is usually slight, they are ignored in most places. Jack reports that in Malaya they destroy enough seedlings on ground not submerged to make it worth while to kill them by the use of poisoned bait.

Thysanoptera.—Thrips, specifically *Thrips oryzae*, Bagnall, in Madras and the Philippines, have been reported on rice several times, but not as doing much injury.

Hemiptera.—A very large number of bugs live on rice, and some of them are among its worst enemies. Of *Nephotettix apicalis*, Motsch., known from Durban to Japan and Hawaii, Baker writes with regard to the Philippines :

> This widely distributed and very abundant species probably pulls down yields as much as or more than any other pest. The millions of them, all sucking the juices of the plants, reduce vitality and health, although they leave little visible signs.

It is described in the "Fauna of British India" (*Rhynchota*, vol. iv., by Distant, pp. 339-362) as a small bug, only 4 to 5 mm. long, with narrow compressed body and broad and broadly rounded head; yellowish green, smooth, and shining above, except for the posterior one-third of the outer wings, which, like the legs and under-side, are mostly black—"One of the small green insects that suddenly appear towards the end of the rains (September, usually)." Shiraki, in *Injurious Insects of Formosa*, vol. i., plate 42, figs. 9, 9*a*, 10, shows the male without the black tail-end and both sexes with brownish legs.

Misra [1] states that a hopper of this genus appeared in 1913 and in 1914, and did serious damage in the Raipur and Bilaspur districts. It appears in July in small numbers, and deposits its eggs on the leaves. These are whitish, flattened at one end and pointed at the other. By the beginning of September the plants swarm with the hoppers—100 to 150 young ones on the single leaves. The plant becomes a pale-yellow colour and withers without producing any grain. The whole life is passed on the rice, the adult hiding under the leaves by day and feeding at dusk. They exude a large amount of a sticky substance, which is overrun by fungi, spoiling even the straw. As means of control Misra suggests: planting early and hardy varieties, such as *harhuna*; sweeping the seed-beds and fields in July and August; the use of light-traps and fires; and grazing the fields after the harvest.

Other *Fulgoridae*, *Jassidae*, and *Cercopidae* listed in the Orient are: *Dictyophora sinica*, Walker; *Diostrombus politus*, Uhler; *Nisia atrovenosa*, Leth.; *Delphax furcifera*, Horvath; *Zygina maculifrons*, Motsch.; *Cicadula fasciifrons*, Stal; *C. 6-notata*, Fallen; and *Tettigonia viridis*, Linn., the preceding from Formosa and the Orient in general; *Zygina subrufa*, Motsch., and *Ptyelus costalis*, Walker, from Formosa; there also, *Deltocephalus dorsalis*,

[1] Misra, C. S., *The Rice Leaf-hopper* (Nephotettix bipunctatus, Fabr.) *in India*, Shalom Press, Nagpur, 1915, 8 p.; *Inter*[illegible] 1915, p. 111[illegible].

Motsch.; *Tettigoniella oryzae*, Dist., in India, and *T. spectra*, Dist., in India and the Philippines.

Trichocentrus gibbosus, How., and *Collaria oleosa*, Dist., are described as destructive to rice in Colombia.

Cicadellidae (and perhaps undetermined *Delphacidae*) injure and occasionally destroy rice locally in Java and Sumatra. Their effects are known as *omo wereng*, which finds some mention in every year's reports.

Plant lice are little known on rice, but two have been found on its roots in the Philippines, *Tetraneura oryzae*, van der Goot, and *Dryopeia hirsuta*, A. C. Baker. The latter, according to Silayan, does considerable damage to upland rice. The attacked plants turn yellowish and are easily pulled up, and valueless.

Of *Capsidae*, only *Lygus oryzae*, Matsumura, is known on rice.

Of *Lygaeidae*, a *Geocoris* is reported as occasionally devastating fields here and there in Indo-China—at Soctrang in 1909, Cantho in 1914, Lonxuyen in 1915, etc.

Leptocorisa acuta, Thunb., is regarded in most parts of the Orient as *the* rice bug. This pest has been reported from India and China across the Sunda Islands. In all this region there is probably no considerable area of rice entirely free from it; and where it is present, there may be no field safe from its attack. It is called *atañgia* in Tagalog, and by similar names in other Philippine languages; in the Dutch writings its name is *walang sangit*. The damage it does varies from insignificant to complete destruction; the latter is not common, but is occasionally reported. The loss of 5 to 25 per cent of a local crop is no rarity, and local in this sense is anything from a single field to many thousand acres. The commoner form of this insect in India is described as *L. varicornis*, Fabr., but the two forms are very doubtfully distinguishable. Uichangco [1] has given it a very thorough biological study.

[1] Uichangco, L., "The Rice Bug, *Leptocorisa acuta*, Thunberg, in the Philippines," *Phil. Agric. Rev.*, 14. (1921), 87.

It is a slender, brownish-olive bug, about 16 mm. (two-thirds of an inch) long, with antennae the same length, hind legs a little longer, and other legs shorter. Rice is its favourite food, but it can live on various wild grasses. If rice is available, the adult bug always leaves other hosts for it. It sucks its food from soft immature kernels, and can attack rice in the milk stage only. To do this it punctures the glumes near their edges, where puncturing is easiest, and then spends about an hour sucking out its food. Rice varieties are unequally subject to puncture, awned rices being, as a group, relatively immune. A punctured grain never matures. In a mild attack only occasional grains are blasted in this way. If the bugs are very numerous, and many or all of the kernels are sucked, the panicle remains white and erect, like that produced by straight head, or by a borer, or sometimes by *Sclerotium*.

The adult insect usually lives for sixty to one hundred days or more, the female averaging longer than the male. She deposits from none to twenty or more eggs a day, a total average per individual of more than two hundred. Each day's deposit is made at one time, after six o'clock at night or before six in the morning, in one or two rows, on or near the midrib, usually on the upper surface of a rice leaf, and not near the tip. The concave under-side of the egg is fastened to the leaf by a gluey substance. The egg is $3\cdot5 \times 2\cdot5$ mm. in size, dark-reddish-brown with a white spot at one end. It hatches after six to eight days.

Being a bug, this insect does not go through distinct larval and pupal stages like a beetle or moth. From the time it emerges from the egg until it becomes adult it is called a nymph. During this time it grows from 1·5 mm. to 16 mm. in length and moults five times. It begins to feed a few hours after hatching, and lives on the same food as the adult. At first it has no sign of wings. These begin to develop after the second moult, but are useless until it is adult. The nymphs can get about only by walking, and therefore spend the most of

their time on the rice panicles where they feed. Hot dry weather seems to be bad for them.

The means of restricting the damage done by this bug are various, but not notably efficacious. The most obvious is by direct attack. In India the principal method recommended is by sweeping the field with long shallow bags, coated on the inside with a sticky substance; the flat baskets used to winnow rice, coated on the inside with bread-fruit juice, are used in the same way. Something can also be accomplished by picking the egg clusters, especially if the fields are gone through anyway, in weeding. Trapping by any method in use is probably ineffective. In some parts of India a mixture of bran and *gur* is used as bait, and in the Philippines decaying meat is sometimes used. An idea of the effectiveness of the latter as bait is given by the fact that another reason given for its use is that its offensiveness drives the bugs away. Other supposed repellents are also used—most commonly smoke, particularly of resin, both in India and the Philippines. Spraying is impractical. And not much is to be expected of another Indian method of accomplishing the same purpose, by dragging across the field ropes saturated with resin or kerosene.

The measure of immunity inherent in bearded rices is sufficient to go far in offsetting the objection to these rices on other grounds where the bug is prevalent. Aside from the bearded ones, varieties are unequal in their resistance to puncturing. Selection and breeding therefore offer a very good prospect of lessening damage by this pest. But it is to be anticipated that immune varieties, however selected and bred, will be behind the best other varieties in yield of clean rice by the unit of rough rice.

Leptocorisa is probably held in check everywhere, more than is generally recognized, by its natural enemies. *Cicindela sexpunctata*, Fabr., destroys many rice bugs in India and in Tonkin; it is reported in the Philippines, but not in this connection. Egg parasites are reported

in India, Java, and the Philippines. In the last country the parasitization of eggs brought in from the field has run as high as 25 per cent. The artificial breeding of a parasite to attack a pest where both are indigenous would not be a promising task, and it is likely that the rice bug is accompanied by very much the same parasites throughout its range. Still, these parasites merit better acquaintance, and effective but local ones, worthy of wider distribution, may be found.

The most promising of all ways of reducing the damage by this bug, at least in the Philippines, is by getting rid of its other hosts. This is really two jobs—clean weeding of the rice itself and freeing the neighbourhood of them as far as may be practicable. The common barn-yard grass, *Echinochloa crus-galli*, L., a rice weed everywhere, is one of the grasses on which the rice bug can pass its whole life; and the equally wide-spread sedge, *Cyperus Iria*, L., can support it at least for a time. The barn-yard grass, in its typical form, blossoms long before the rice. If allowed to grow in the rice field it gives the bugs a chance to establish themselves and multiply there, against the season when the rice will be ready for them. The boundaries between the little individual fields (not the single paddies), especially in upland rice, are very generally overgrown with grass and brush; and these hedgerows afford very good breeding places for bugs when rice is not to be had. When the rice is ready the adults fly into it from these boundary-lines. Immigration from outside the rice is the only reasonable explanation of the proportion of ten adults to one nymph, observed by Uichangco in one field. When the College of Agriculture was established, its land was cut up by many hedgerows, and the bugs prevailed over the rice completely enough to vitiate experiment after experiment. After a year or so these divisions were cleaned out, and damage by bugs decreased at once.[1]

[1] Cevallos, F., in *Phil. Agric. and Forester*, 1. (1911), 87. *Panicum auritum* and *Rottboellia exaltata* are specified as among the wild hosts.

Finally, the most common of all means of escaping serious damage from bugs is by appropriate timing of the milk stage of the rice. The aim is, of course, to avoid the period when experience has shown that fields are most likely to be seriously damaged. This is not the same in different countries, nor even in different districts, so no attempt will be made to specify it. In some places there is some degree of regularity in the time of greatest abundance of the bugs, depending presumably upon weather, food supply, and parasites, independent of the rice season. If rice can be timed so as not to be in the milk when the bugs are most numerous, this is of course done. Another aim is to not have single fields in this stage by themselves, lest they be beset by all the bugs in the neighbourhood; but rather, so far as the impossibility of harvesting it all at once does not prohibit, to have each man's rice susceptible when great areas are so, and thus let the damage be spread out and more easily borne. The general economic gain by this practice is in feeding fewer bugs and feeding them for a shorter time.

The damage done by bugs of the family *Pentatomidae* is known in Java as *omo lembing*, and consists of an attack on the rice stems, which keeps the grain from ripening. The identified species are *Ancestis histrio*, *Nezara viridula*, *N. griseipennis*, and *Podops vermiculatus*, as listed by Rutgers. Of these, *Podops* is most frequently reported in both Java and Sumatra. "Omtrent de wijze van bestrijding tast men nog in het duister." Low and poorly drained paddies are said to suffer most, but clean seed-beds have been ruined by it. Jack cites *P. coarctata*, a black bug half an inch long and a little narrower, as a pest in Malaya. When the rice is flooded the bugs float. The *Nezara* has been reported on rice in the Philippines and Formosa also. Other bugs of this family on rice are *Aenaria lewisi* in Japan and *Plantia affinis*, Dallas, in Australia (according to Pierce).

In Louisiana and the neighbouring states, rice in the milk and soft dough is attacked by three identified

Pentatomidae: *Oebalus* (or *Solubea*) *pugnax*, Fabr.; *Euschistus tristigmus*, Say; and *Proxyx punctulatus*, Pal. Beauv.,[1] of which the first is by far the most injurious. This bug "is brown, $\frac{1}{2}$ inch or a little less in length and $\frac{3}{16}$ broad; its general outline may be described as coffin-shaped. Posteriorly thin portions of the wings are exposed." Here and there, late in the season, they may become numerous enough to puncture practically every grain of rice which is not yet too hard for them. The whole life-cycle may occupy only two weeks, so that a considerable number of generations can mature during a season. They can live on various other grasses, and the great fluctuations in their number from season to season and place to place may be due both to varying opportunities to multiply on other hosts, and to the work of their natural enemies. Too little is known about the whole biology of this bug to provide a foundation for directions for holding it in check.

As to the effects of its attack, if grains are punctured in the early milk stage, they shrivel and effectively abort. If the attack is made later, the commonest result is a definite brown spot. Fungi follow the puncture if it is early, and bacteria alone if it occurs after the kernel begins to harden. Fulton ascribes the real damage to the fungi and bacteria rather than to the puncture by itself; but as there is no possibility of avoiding the presence and entrance of these organisms if punctures are made, the only possibility of avoiding damage is by finding a way of reducing the number of the bugs.

Neuroptera.—The larvae of *Triaenodes bicolor* are reported in Italy as cutting the leaves of rice and other aquatics to make their covers.

Coleoptera.—The beetles which destroy most rice, by attacking the stored grain, will be mentioned at the end of this list, but a considerable number are minor pests of the growing crop. A coccinelid, *Epilachne* or a near relative, is reported by Vincens as occasionally attacking

[1] Fulton, *l.c.*, *Louisiana Bull.* No. 105, p. 13.

rice in Indo-China, perhaps when its other normal food is scarce. A *Cicindela* is reported in India and in Tonkin. Of *Scarabaeidae*, *Anomala vitis*, Fabr., and *Phyllognathus dionysius*, Fabr., do considerable damage in India by boring in and destroying the roots. *A. atrovirens* is reported by van Hall in 1916 on upland rice in Sumatra. In Louisiana *Euetheola rugipes*, normally a pest of maize, has been reported on rice also. *Chalepus trachypygus*, Burm., called the rice grub by Austin, feeds on the rice roots in all its stages. It has no other host as far as known, but attacks the rice only when it is not flooded, and flooding puts an end to its activity.

A number of *Chrysomelidae* are rice pests, of which the worst are species of *Hispa*. *H. aenascens*, Baly, "the rice hispa," [1]

> a small blue-black beetle covered with spines, occasionally causes damage to the rice crops in India. It sometimes appears in enormous swarms, and then causes wholesale destruction. Usually it feeds on the young rice plants in seed-beds or in newly planted fields; it eats the cellular tissues but rejects the fibrous vascular bundles, and as a result of its attacks the plants assume a white and withered appearance. The eggs are laid singly in the tissue of the leaf, and the whole life of the beetle is spent within the leaf until the mature insect emerges.

It feeds normally on wild grasses, which it leaves for rice. As preventive measures, it is recommended that wild grasses be kept down near rice fields, that seed-beds be watched for the eggs, and that the time of transplanting be adapted to the danger of attack. At the Sibpur Experimental Farm, dipping the seedlings in a solution of asafoetida when transplanting protected them. Soft-leaved varieties are most subject to attack. After the stem-borer, this is regarded as the worst pest of rice in the Konkan. Collecting the eggs is recommended, especially as those of various other pests will be gathered at the same time. Light-traps are

[1] Anon., "The Cultivation and Preparation of Rice," *Bull. Imp. Inst.*, 12. (1914), 86.

effective on dark nights, but should be used near, not in, the rice fields, else they are likely to do more harm than good. They need not be of great power; a light of 20 c.p. caught more beetles than one of 1000 c.p.

Chaetocnema basalis, Baly, is reported as an Indian rice pest. A species of this genus is reported in the Philippines by Reveche.[1]

In September 1921 this species was found in large numbers on young upland rice, leaving the rice when the grain became mature. The upper surface of the leaf was eaten, parallel to the veins, the leaf later turning yellow and drying up.

Hispa callicantha and *Lema flavipes*, Suff., are reported in Japan. *Diabrotica 12-punctata*, Oliv., normally a parasite of maize, sometimes kills rice in Louisiana.

Of the weevils, the rice water-weevil is present in all fields in the Southern United States.[2] According to its abundance, it does little or much damage, rarely killing the rice. The adult beetle is of the colour of dead grass, and hibernates in dead grass or sometimes in Spanish moss; it becomes active again at any time from March to June, and enters the rice at the time of the first irrigation. It gnaws the leaves, eating off strips and leaving only the epidermis, but does no great damage in this way. It seems to fly only at night. To deposit the eggs the female crawls down the stem to the root, where it inserts one to three eggs under the epidermis. The larva remains in the same root for some days after hatching, eating it out lengthwise. When this root is used up, the grub is large enough to hunt another, so destroying them in succession. The full-grown larva is $\frac{1}{4}$ to $\frac{1}{2}$ inch long, milk-white, and very slender. It pupates inside a smooth ovate mass of dirt attached to a healthy rice root. At the end of the pupal

[1] *Phil. Agric.*, 11. (1922), 42. Also in Woodworth's Host Index, *ibid.* p. 53.

[2] Webb, J. L., "Notes on the Rice Water-weevil (*Lissorhoptrus simplex*, Say)," *La. Agric. Exp. Stat. Bull.* No. 172, 1920. Also in *Journ. Econ. Entom.*, 7. (1914), No. 6.

stage the adult breaks out, crawls up into the air, and flies away. The life-cycle probably lasts about thirty-eight days.

There are two measures recommended for minimizing the damage. One is to drain the rice after not more than two weeks and let the field dry out thoroughly. The other is the application of crude oil on the first water. In experiments the application of twenty gallons of oil per acre resulted in a crop of 22·6 barrels, as against 16·8 barrels by the check plot. Fifteen gallons to the acre is sufficient. If oil is to be used, the first irrigation should be delayed as long as is safe.

Echinocnemis squameus, Billberg, damages rice in Formosa in the same manner. *Hypomeces unicolor*, Fabr., and *Athesapeuta oryzae*, Marshall, are reported in Java and Madras respectively.

Webb [1] reports that *Sphenophorus oblitus*, Lec., attacked rice on new land in Texas, and suddenly "destroyed large plantings. But it disappeared as suddenly when the new rice was flooded, and never has been heard of since."

Lepidoptera.—An idea of the number of moths and butterflies which live on rice is given by the fact that Duport [2] found 35 of them in Indo-China alone. The most feared of them are the stem-borers, belonging mostly to the family *Pyralidae*, and regarded in many parts of the Orient as the worst enemies to which rice is exposed.

The most widespread and generally destructive paddy borer is *Schoenobius incertellus*, Walker, also known as *S. punctellus* and *S. bipunctifer*. Thus Kasargode and Deshpande [3] state that in the Bombay Presidency *Shir* (its Marathi name) does more damage than all other pests

[1] Webb, J. L., "How Insects affect the Rice Crop," U.S.D.A., *Farmers' Bull.* No. 1986, 1920.

[2] Duport, L., "Les principaux parasites du riz en Indochine," *Journ. d'Ag. Trop.*, 14. (1914), 204. This is the author's digest of a detailed treatment in *Bull. Econ. Indochine* (1912), 781-803 (1913), 306-376, 947-1002.

[3] Kasargode, R. S., and Deshpande, V. G., "The Rice Borer in the Konkan," Dept. Agr. Bombay, *Bull.* No. 69 of 1915, 18 p.

combined. The damage is rarely less than 10 per cent and may reach 60 per cent. Figuring 10 per cent and 3000 lb. of rough rice to the acre, the annual destruction on the 1,560,000 acres in the one presidency is over four hundred million pounds. In one district of Java (Cheribon) the damage by borers in 1915 was effectively total on 14,000 bouw. Its natural enemies most effectively limit its ravages, and it is as it happens to be locally and temporarily free of these that exceptionally bad outbreaks occur.

The adult is a straw-yellow moth, with one black dot on each fore-wing. The body is about half an inch long and the wing expanse about an inch. The eggs are laid at night, on rice or other grass, in masses of 40 to 220. The single eggs are very small and almost white, but the masses are a bright yellow because covered with hairs of that colour. These masses are a fifth of an inch broad and up to three-quarters of an inch long, and because of their colour and size are easily seen and collected. They hatch after six or seven days. The young larva is black, with a big head. At first it eats strips off the surface of the leaf; but when a little over a day old it finds its way to the base of the leaf, and bores into the stem. As many as a dozen may be found in one stem. The larval stage lasts twenty-seven days in the Konkan. The full-grown larva is about an inch long. Feeding upward, it finally emerges near the top of the stem, and makes for itself a shelter by cutting and rolling a leaf. After spending perhaps a week in this, it returns to the base of the stem, bores in again, and there spins its cocoon. After ten to twelve days the moth emerges. The whole life-cycle occupies about forty-two days in the Konkan.

Next in destructiveness to the *Schoenobius* on the whole, of the borers, are several species of *Chilo*: *C. auricilia*, Dudgeon, in India and Malaya; and *C. simplex*, Butler, in India and Japan; *C. suppressalis* and another species in Indo-China; still others in the Dutch Indies; and *C. prejadellus*, Trinck, in the Southern United

Fig. 1. Chilo spec. A.

1a. Female, wings expanded, natural size.
1b. Female, in posture of repose, magnified.
1c. Cluster of eggs, natural size.
1d. Larva, considerably magnified.
1e. Pupa, magnified.

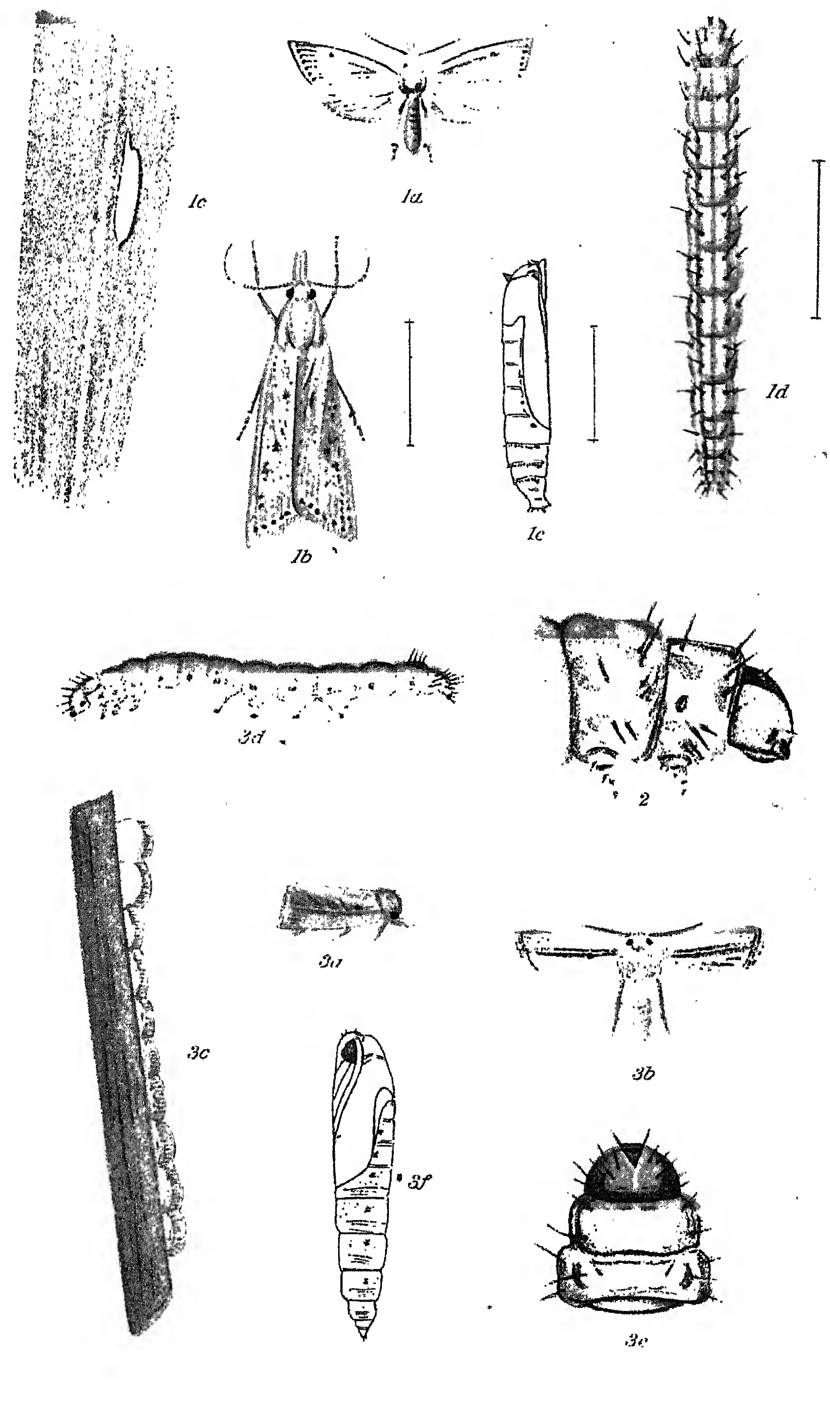
Fig. 2. Chilo spec. B.

Head of the larva, much magnified.

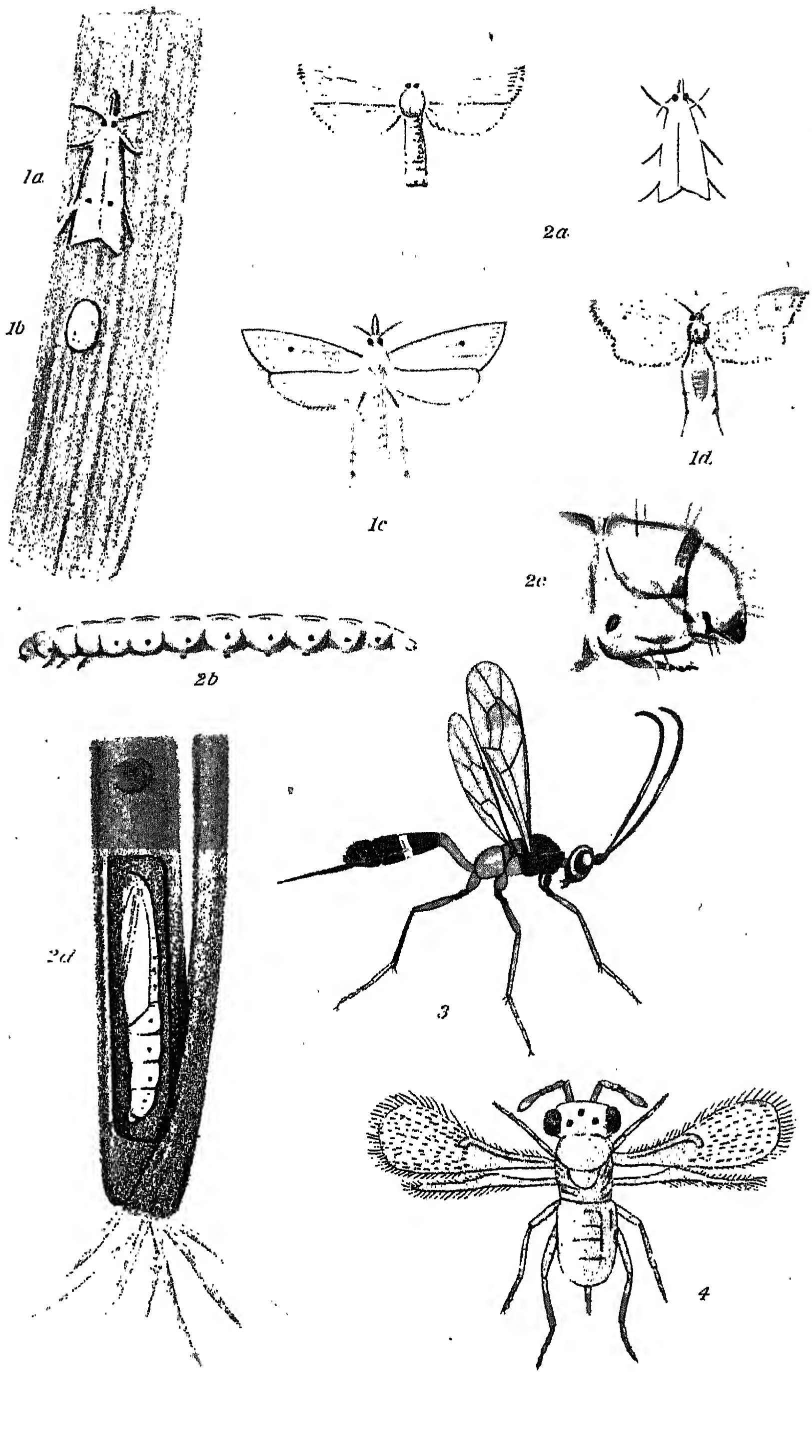
Fig. 3. Sesamia inferens Wlk.

3a and b. The moth, natural size.
3c. Eggs, much magnified.
3d. Larva, × 2.
3e. Head of larva, much magnified.
3f. Pupa, × 2.

From K. W. Dammerman.



1c
1a
1d
1b
1e
3d
2
3a
3b
3c
3f
3e



1a
1b
2a
1c
1d
2c
2b
2d
3
4

FIG. 1. SCHOENOBIUS BIPUNCTIFER Wlk.

1a. Female, on leaf, natural size.

1b. Cluster of eggs, natural size.

1c. Female, wings expanded, natural size.

1d. Male, natural size.

FIG. 2. SCIRPOPHAGA SERICEA Snell.

2a. Moth, natural size.

2b. Larva, × 2.

2c. Head of larva, much magnified.

2d. Pupa in rice stem, with port of escape.

FIG. 3. An ICHNEUMONID parasite of SCIRPOPHAGA, × 3.

FIG. 4. TRICHOGRAMMATOIDEA NANA Zehnt., an egg-parasite of the borers, much magnified.

From K. W. DAMMERMAN.

States. The last[1] is a pale-yellow moth with golden patches and scales, having as a distinctive mark a row of seven black spots at the end of each anterior wing. Its larva is whitish, with subdorsal reddish-brown stripes. It feeds on the inside of the stem, emerging occasionally and re-entering lower down. Finally, when about an inch long, it pupates an inch or so above the last hole made. It is preyed upon in the pupal stage by the larva of a fly. The larva of *C. auricilia* is whitish, with a black head and purplish-brown stripes; that of *C. simplex* has small brown spots on the segments.

Other borers of the same family are *Scirpophaga sericea* and *S. chrysorrhoea*, in the Dutch Indies. Dammerman[2] has made a remarkably thorough study of the borers of Java, and instituted a campaign of education for the restriction of damage by them. The accompanying illustrations are his drawings, taken from the publication cited, and using his names.

Noctuid moths of the genus *Nonagria* (or *Sesamia*) also have stem-boring larvae. *N. inferens*, Walker, ranges at least from India to Formosa and Java, and is typically a rice borer. Its larva is uniformly pinkish. *N. uniformis*, Dudgeon, reported from India, Celebes, etc., is commoner on other cultivated grasses, but can attack rice.

The work of all the borers is the same. They may attack the rice in the seed-beds, or at any later time. The stem is killed from the point of entrance upward, and so can produce no grain. They are preyed upon by a variety of enemies, spiders and ants eating the eggs and young larvae, and parasites of several kinds being reported as destroying a considerable part of the larvae and pupae. There is no evident way of promoting the work of these parasites. Direct measures of control fall into three groups: Hand-collecting the eggs, which, if carefully done, gets rid of many kinds of pests at once;

[1] L. O. Howard, in Austin, A., "Rice: Its Cultivation, Production, and Distribution," U.S.D.A. Div. of Statistics, Misc. Series, *Report* No. 6, 1893.

[2] Dammerman, K. W., "De Rijstboorderplaag op Java," *Meded. van het Lab. voor Plantenziekten*, No. 16, 1915. (With a summary in English.)

clean culture of the paddies and surrounding land, getting rid of other grasses on which the borers may multiply or live actively while rice is not available ; and burning the stubble. The last has been widely advocated, and sometimes been proven effective ; but the Konkan study already cited showed that *Schoenobius* hibernates so far down among the roots that even as thorough burning as *rab* preparation of the seed-beds (see p. 271) does not kill them all. A difference in the species present may account for the greater effectiveness of burning the stubble elsewhere. In parts of Java, the Government has provided seed of other crops to take the place of the pasture lost by burning. Early and thorough cultivation after burning adds essentially to the effectiveness of the effort. When borers attack the seed-beds, it is decidedly safest to use no seedlings from those attacked, if this is possible. To be really effective, all such measures must cover considerable areas, without intervening untreated spots.

Harukawa [1] experimented in laboratory and field with the control of borers by submergence. Inside tests showed that immersion for fourteen hours at 35° C. kills practically all (99·2 per cent) larvae, and that twenty-four hours at 30° kills 97 per cent. In the field experiments only 4 to 6 inches of water could be used. If the free movement of water is stopped, the temperature of water in the field ranges from 24° to 28° at 8 A.M. to about 36° in the afternoon. Under these conditions, if submergence is complete, practically all larvae are killed ; but if it is incomplete, the mortality is only 10 to 40 per cent. Complete submergence was accomplished by forcing the rice down into the shallow water. A paper in Japanese, by Nakagawa, is cited, showing that *Schoenobius* larvae which have over-wintered can be exterminated by prolonged submergence in the spring.

Since Dammerman's publication, work has been done

[1] Harukawa, C., "Controlling the Rice Borer (*Chilo simplex*) by Submergence," *Ber. Ohara Inst. f. Landw. Forsch.*, 1. (1920), 599.

in Java also on the control of borers by submergence.[1] The problem there is very different because of the comparatively rapid decay of the stubble; as decay becomes advanced, quite complete extermination is possible by submergence for three weeks.

Beside the stem-borers, the family *Pyralidae* contains several leaf-rollers: *Nymphula depunctata*, Guenee, from India to the Philippines and Australia; *N. fluctuosalis*, Zeller, in India; *N. stagnalis* in Java; *Cnaphalocrocis medinalis*, Guenee, in Indo-China and the Philippines; *C. jolinalis* in the Dutch Indies; *Marasmia venilialis*, Walker, in the Philippines; and *Nymphula* (or *Hydrocampa*) *nympheata* in Italy. The larvae of the last live in water, feed on young rice plants, and cut the leaves to make shelters for themselves. The destructive work of these insects consists chiefly in stripping the leaves, so that they turn white, wherefore their work is known as *omo putih*, the white disease, in Java. *Cnaphalocrocis* folds, instead of cutting and rolling, the leaf to make its shelter. All of these are sporadically serious pests, as they happen not to be held in check by other, parasitic or predacious, insects. The reports on these insects are decidedly conflicting. Thus Duport states that *Cnaphalocrocis* is the worst of the borers in Tonkin, the average damage to "tenth-month rice" being 5 per cent or more, while in the Philippines it is not regarded as a borer at all. And while draining is recommended in Southern India for the control of *Nymphula*, deep submergence is an approved measure against all of this class of insects, because they drown readily. Sweeping the fields with nets, as recommended for the control of bugs, catches many of these insects also.

The larva of *Artona walkeri*, Moore, a Zygaenid moth, is said by Duport to do considerable local damage occasionally in Tonkin.

Army worms attacking rice are *Spodoptera mauritia*, Boisd., from Africa to the Philippines and Australia; *Prodenia litura*, Fabr., with almost the same range;

[1] *Jaarboek van het Dept. van Landbouw*, etc., 1916, p. 26; 1918, p. 142.

Leucania unipuncta, Ham., in the Philippines and Java; and *Laphygma frugiperda*, S. and A., in the Southern United States. The attacks of these worms are only sporadic, but may be completely destructive. They eat whatever they come to, but a swarm is likely to be headed off by a bare zone a few metres wide, cleared around the rice, or better yet by a trench. Other measures are deep cultivation and covering the water in the paddies with a little oil and then sweeping the rice to knock the "worms" off. Other insects and birds usually keep army worms from multiplying to great armies. If the insect-eating birds had not been so largely killed off in the chief rice-producing lands, the damage from insects as a whole would be much less than it is.

The rice skipper butterfly in India and the Philippines is *Parnara mathias*, Fabr. Other skippers in Java are not reported by name. *Melanitis ismene*, Cram., is called the rice butterfly in the Philippines. It lives in folded leaves, and eats them from the ends downward, but is never numerous enough to be very destructive. Rutgers reports *M. leda* in Java, and with it *Cirphis unipunctata* and *Psalis securis*, and says that these sometimes do much damage there.

Diptera.—A *Cecidomyia* is frequently reported in the Dutch Indies, where the injury it causes is known as *omo mendong*. It attacks seed-beds chiefly. *Aetherigona exigua* attacks upland rice in Java. Damage by unidentified larvae of flies is occasionally reported in other countries.

Insects in Stored Rice.—The annual damage by insects to stored milled rice is very great indeed. Paddy rice is much less subject to such attack and not often kept so long in storage, but the damage to it also is very considerable. The worst such pest is the cosmopolitan rice weevil, *Calandra oryzae*, L. Other widespread beetles are the long-headed flour beetle, *Latheticus oryzae*, Waterb.; *Silvanus surinamensis*, the saw-toothed grain beetle; and the Siamese grain beetle, *Lophocateres*

pusillus, Klug. *Alphitobius piceus*, Oliv., in the Philippines; *Tenebrioides mauretanicus* in Japan and elsewhere; *Laemotmetus rhizophagoides*, Walker, in Ceylon and Germany; and *Tribolium castaneum* in Malaya, all do the same mischief. The larvae of several moths and butterflies do similar damage. *Melissoblaptes gularis*, Zeller, in Japan and England; *Paralipsa modesta*, Butler, in Japan and thence in Hawaii; *Sitotroga cerealella*, Oliv., in the Philippines and Malaya; a *Tinea* in Java; *Ephestia cahiritella* in Mauritius; and *E. Kuhniella* in Malaya, are reported in this connection. The most of these attack cereals in general. The *Ephestia* destroys dried fruit and nuts, and is called the dried currant moth in the United States, but in Mauritius is said to spoil white Saigon and Rangoon rice, but rarely any other kinds. The way of handling all of these insects, once they are present, is by the use of poisonous gas, most often with carbon bisulphide.

D.—OTHER ANIMALS

Crabs.—Austin reports that in Sindh a small black sea crab, "without any apparent object, cuts down the growing grain in large quantities." Some damage by crabs in Madras is reported by Ayyangar.

Snails.—The same author states that in Kashmir a small snail destroys the young seedlings. If it does too much mischief, so that re-sowing is necessary, the seed is broadcasted into the water, and a vegetable poison is also thrown in to kill the snails. The snail *Physa acuta*, Drap., is "a terrible enemy of rice fields" in Portugal,[1] and occasionally does mischief in Piedmont and about Amposta in Spain, where it is called *caragoli*. In Portugal, where rice is not transplanted, they have tried germinating the seed before scattering it, to shorten the time in the field during which the seedling is tender enough to be subject to attack, and this has helped somewhat. In Italy the water is withdrawn from the

[1] Valencia Rice Congress, *Actes*, p. 316. Remarks by Rasteiro.

infested paddies for two or three days of bright weather, and ammonium sulphate may be applied. In Spain, where the snails are present, the practice is to apply slaked lime, a ton and a half or two tons to the acre, which "is absolutely infallible, as well against the caragoli as against all other insects whatever." But transplanted rice is safe from their attack in the field.

Rodents.—Rats, mice, moles, voles, etc., are among the most destructive enemies of rice in all lands, both of growing crops and of harvested and stored rice. In the fields these are the various local species chiefly, while the rats and mice which have accompanied commerce over the world are the worst enemies of warehoused grain. The latter are kept down by means of virus, poisons, and cats. The most effective enemies of the native rodents in most places are the snakes, wherefore the general human disposition to kill every snake should be educated to spare, as a real friend, every non-venomous one. The predacious birds whose natural food is not other birds should also be spared and protected.

In a few places semi-aquatic rodents are rice pests; when rice was an important crop in Carolina, one of these did great damage to it. Most rodents, however, have only a limited ability to adapt themselves to the presence of water, so that the culture of paddy rice tends to limit their numbers. They are therefore most troublesome where rice is scattered, rather than planted continuously over great areas. In rice-land itself they are restricted to the dikes as places to live and breed, and can be attacked there. They have been notably destructive in the Malay States, where the Department of Agriculture made a study of their habits and of means of control.[1] Living only in the *batas* or dikes, they spend the midday hours in their holes. The Department secured a supply of carbon bisulphide, which it issued to the planters in beer-bottles. The directions were to

[1] Gallagher, W. J., "The Extermination of Rats in Rice-fields," Dept. Agr. F.M.S., *Bull.*, No. 5, 1909.

find the holes, put 0·5 c.c. of the carbon bisulphide on a piece of kapok half the size of an egg, stick this six inches down into the hole, and close the hole tightly. If systematically undertaken, the extermination of rodents is a much easier problem than the control of insects.

Birds.—Birds are everywhere pests of rice, and are its most destructive foes in many places. Some of these are widespread or closely related, as the species of *Munia* in the Orient, while others are more local; but all do the same damage and are fought in the same ways. Actually guarding the fields is the most effective of these, and the use of scarecrows is next, so far as protection of single patches is concerned. Having congested rice patches spread over an expanse of country without other food for the birds, the Igorot peoples are especially exposed to the destruction of their rice by the birds, and besides watching their fields so far as their numbers permit, have become specialists in the use of scarecrows. They make large imitation birds, hung in a life-like manner from the tips of slender bamboos stuck into the ground at an angle and scattered thickly over the fields. The bamboos are then connected by home-made ropes, so that a guard can jerk a main line and make the "birds" flutter over a considerable area. Near streams the agitation of the scarecrows is made automatic by using a convenient branch or a long bamboo spring on each bank, tying a float between these so that the stream will carry this down to a distance of several feet or yards and then let it snap back in the air, and connecting the branch or bamboo spring with the system of lines over the paddies. The scarecrows are thus kept constantly agitated. Pieces of bright tin, flashing in all directions, are also in effective use in the place of imitation birds.

Trapping and otherwise killing the birds is also practised everywhere, but is a slow means of protecting rice, and not at all effective except where done by a dense population during many years. Firearms, of course, both scare and kill the birds, but the rice-growers

of the Orient do not have many of them, nor much ammunition.

In the Southern United States the "rice-bird," *Dolichonyx oryzivorous*, has been by far the most destructive single bird enemy, but a number of others, there and in California, do great damage both to the ripening grain and to broadcasted seed and even to young seedlings. The ubiquitous English sparrow has also developed into a rice pest in some places. Nothing but killing will control it.

Typical water-fowl also destroy rice—a limited amount, as some of them sometimes breed in rice-land and do a little constant damage—but chiefly as swarms of migratory kinds befall it as it ripens. Two ducks do this in the Philippines, and a variety of ducks and geese do great damage during some harvests in California. Protection of these birds, not merely by local law but by treaty, keeps hunters from helping the rice-growers to protect the rice while the greatest damage may be done. Very early rice is harvested before these birds arrive in great numbers, and the avoidance of any open water in the fields usually keeps them from coming down during the early fall. The most spectacular method of protection from them has been by the use of aeroplanes.

Other Animals.—Wild hogs and monkeys are dangerous enemies of rice where the population is sparse and a part of the country remains in jungle. And loose domestic stock of course does damage whenever it has the chance.

Finally, and in none of the preceding classes, there has been observed in the Dutch Indies a weed, *Striga*, which deserves particular mention, because, unlike all other weeds, it does not merely crowd the rice and compete with it in the usual ways, but is parasitic on its roots.

CHAPTER IV

SEED AND VARIETIES OF RICE

WHILE the subject of the varieties of rice is so vast that the present information on the subject would make something of a book by itself, and the things that ought to be known might make a set of volumes, it is still in its practical aspects so intimately associated with that of the choice of seed that it is convenient to treat the two subjects together. One reason for this is the fact that most of the named varieties are themselves mixtures of kinds of rice, among which there is just as good reason for making a choice as there is for choosing the variety to be planted.

No problem of the rice-grower is more important than the choice of his seed. More than anything else, this determines what his crop is to be. And, more than any other factor in determining his crop, this one is under the grower's cheap control. The climate he cannot alter, and can foresee only imperfectly. His soil is usually determined in advance, and is subject only to expensive modification. He chooses his seed in adaptation to his climate and soil, and to his prospective supply of water. The preparation of the soil and the care of the growing crop are of course likewise important, but within the limits that will permit any reasonable crop, less so than the choice of seed, and they offer the grower much less freedom of choice.

Care and Local Choice.—Regardless of the variety, the seed should be clean—that is, free of seeds of other

kinds, especially of weeds; uniform—that is, free of seeds of other kinds of rice; and of good germinating capacity—that is, with a high percentage of germination and vigorous in germination. Old seed loses in vigour as well as in the percentage capable of germinating, and the former loss is often overlooked. As to power to germinate at all, seed in the tropics seems to lose 10 per cent. or more in a year, and rather less than this in California. This loss can be made up for by the use of more seed, and a germination test before the time to plant will show if any increase above the usual amount of seed is needed. Under any unfavourable conditions, such as undue cold, or too much or too little water, weak seed produces a poor stand in a measure out of proportion to the injury done when vigorous seed is used. There are defects in seed, from the miller's view-point, which do not injure it materially for seed; the presence of wheat or barley is an example. And moderately sun-cracked rice may be good seed. But as a general rule it is very poor business to use any rice for seed because it will not sell at the highest price.

Weed seed of most kinds can be removed easily by re-cleaning. Where rice is harvested by hand it is practically sure to be clean. Where binders are used, if the fields are weedy, the seed is almost sure to be unclean. In California warehouses the usual charge for re-cleaning is three dollars a ton; chaff and light and imperfect and broken grains are removed at the same time as the weed seeds. Many growers have their own small fanning mills for this purpose. Wherever planting is done by machinery, whether it be drilled or broadcast, the removal of fragments of straw and broken heads is important, because threshed rice usually contains enough of these to interfere with uniform seeding. The uniformity of clean seed is also important, in order that one may know just what amount one is planting.

It is a general idea, applied to seed of all kinds, that heavy seed—that is, seed of relatively high specific gravity—produces more vigorous plants than light seed.

In many places growers use water in an attempt to separate the light from the heavy seed, skimming off and discarding the floating grains. It has been agreed by all who have given this treatment careful study that it has no value, except as it may hasten subsequent germination. If the selection of seed by weight has any value, it should be effected by means of a solution heavier than water. In Java, lye is sometimes used for this purpose, as are Chili saltpetre and copper sulphate in Spain. The copper sulphate (used in a $\frac{1}{10}$ per cent solution according to Montesoro, and in a 2 per cent solution according to Fort) has at least a germicidal value; it may, for example, protect the crop against blast, but not against the black smut. There is no general agreement that rice from heavy seed has any advantage. And careful study in Java and the Philippines has led to the conclusion that it is not worth while to attempt to secure heavier seed by breeding. Where blast caused by a fungus whose spores may be carried over by the seed has to be reckoned with, the problem is different, and it may well be that the removal of seed made light by the fungus is more perfectly accomplished by a solution than by fanning or winnowing; in this case a disinfecting solution, as of copper, should always be used.

In most places the best growers regularly raise their own seed, and do this to better purpose than they could buy it. In most places, too, many growers do this without advantage, using their own when they would better sell it and buy other and better seed. The alternatives everywhere are to use one's own seed, or to buy it from a neighbour whose crop is better in some respect not clearly dependent upon better field treatment. It is usually wiser to use either of these sources than to buy seed of unknown origin. In some places, as in Italy and Louisiana, there are rice seedsmen who grow rice with proper care, for this particular use; but, the world over, there are very few seed dealers who grow and sell rice seed. Another possible source in most

lands is Government seed, available in small quantities, but sufficient for a test of its local value, and for industrial planting in the second generation if the test is satisfactory. There is no better example of the farmer's typical conservatism than the general failure of growers to secure seed from experiment stations.

As a general proposition seed should not be brought from a considerable distance, except for planting on a very small scale as a test of its value. The great number of rice varieties is an expression of the fact that this grain is highly specialized in adaptation to local conditions. Rice locally grown with good results can be expected to yield well locally, much more confidently than can the most productive rice of some other land. Some of the most remarkably productive seed strains have proved to be most localized in their adaptability.

In every place where considerable rice is grown there are a number, often a large number, of varieties from which to choose; and in making a choice many things must be considered. Some varieties recommend themselves by high yield, others by good milling quality, keeping quality, fine taste or appearance, fitness to soil conditions, freedom from danger from weather, pests, and diseases, ease of harvesting, and in various other ways. The weight to be given to these different items of merit is a purely local business question.

Where rice is raised chiefly for export, it is an advantage to produce single types on a large scale. A large and uniform product can find and hold a market, while a small or unsteady or mixed product may remain at a serious commercial disadvantage. California rice, of a Japanese type, has secured a reputation in Japan which lets it be marketed there in advantageous competition with any other outside rice; but it is not produced on a sufficient scale to hold this market and at the same time hold the market it once had in Cuba, or secure the market it might have in Argentine. Indo-Chinese rice has usually been mixed before it reached the mills; as a result, it is mostly simply rice, not rice of some estab-

lished type, and sells for less than a large part of it might bring if it had an established market and sold on its particular merit. On the other hand, where rice is grown for local consumption on a large enough scale, it may well be diverse, to serve a market of diverse wants and means.

Rices regarded as finest in quality are not usually most productive. This is true of the varieties developed through the ages, and seems to continue true of the strains developed by scientific effort, although, except as long grains are highly prized but mill poorly, there is no known reason why it should be true. Quality is in part something subject to definition, as rice of coarse texture, or real lack of taste, or which cannot be cooked well, can be said to be poor. But it is purely a matter of personal or tribal or regional taste, without any definable absolute element, or custom, without consideration of taste, which makes the California housewife demand a Louisiana rice, imagining that it is "Carolina," while her cook may have his imported from the Orient; and the California product has been so preferred in Cuba, educated by Spain to a taste for its type, that it could pay for freight and handling and be shipped through Louisiana to Havana. Each grower in each place has to decide as best he can what rice will pay him the surest or greatest return; and the factors which should decide him are too purely local to admit of profitable general discussion.

Characteristics of Varieties.—In approaching the subject of varieties and their classification, the first step is to recognize the points of difference, and one's first impression is that every character of the plant and grain is a distinctive one, changeable from variety to variety. This is of course not the case. Rice does not, for instance, vary to the point where its characters approach those of any other grain or grass. But it is true that, within the limits which define rice as a whole, every part of the plant which has been carefully observed has been found to provide characters by which varieties

can be distinguished, and that various writers have imagined that they could recognize the more striking groups of varieties as distinct species.

As plants are usually described, their characteristics are those which strike the eye. They are described as a matter of convenience, and given names as species or varieties, still for the sake of convenience; and an attempt to describe or define them by invisible characteristics would defeat, instead of serve, this end. It is only among the bacteria and parasitic fungi that things look alike but behave differently in respects which concern us so greatly that men have come to the recognition of physiological species. In a perfectly logical sense, all differences are physiological. Returning to rice, one plant is taller than another because it grew faster or grew for a longer time; the grain is slender or round because it grew chiefly in length or grew equally in all directions; if it is red, it is so because a red pigment was formed and deposited there. As a matter of convenience we go by the eye, and describe the plant as of such a height and the grain as so long, of such a shape and colour, and ignore the physiological behaviour responsible for the things we see. As far as is possible we serve our convenience by continuing to give attention to what we see; and in recognizing and describing the varieties of rice, and in trying to classify them, we are forced to do this, because the published descriptions are in these terms, and in large part in these terms only.

But just as in the case of many bacteria, in dealing with the varieties of rice we are very much concerned with behaviour, which never finds expression in characters we can see. Such physiological behaviour as determines the shape and colour of the grain is easily and sufficiently described by the result, as this strikes the eye. But two varieties, of which one requires a growing period of 120 and the other 160 days, or of which one requires submergence and the other does not, may look exactly alike when mature, although in a given

place one may produce a fine crop and the other nothing. Using the word in a very inadequate sense, the characters one sees are sometimes called "botanical," and a classification based on them is called a botanical classification.

It is not known that the varieties of rice vary as to the roots, although it is probable that they do. The floating rices of Cambodia strike root from the upper nodes after the floods subside. Upland and lowland rices differ materially in the root system, but this may be due directly and entirely to the environment.

As to the stems, the capacity to tiller is certainly an hereditary character of varieties; but the number of culms is always so subject to influence by the available space, and the time of tillering, if not the extent also, by the water, that this character, although of real importance to the grower, is not a convenient means of describing or recognizing varieties. The length and number of the internodes, above the very short ones at the base, vary with the variety, and together determine the height of the plant. Although subject to control by the water supply, in both upland and lowland varieties, the height is very generally used in descriptions of varieties, and is important because short varieties are in general light yielders; above a height of a yard or a metre, however, added height is not associated with heavy yield. The internodes of floating rice grow far out of the sheaths. Most rices have greenish-white internodes, which dry to straw-coloured. A few varieties have distinctive other colours or are streaked. Black or red nodes are much commoner; they are usually, but not invariably, associated with coloured hulls, kernels, or stigmas. Stoutness of stem is a very important character, because of its relation to tendency to lodge. To put this character into shape for comparison, measurements are necessary, and very few have ever been made. To secure comparable data, measurements must be at approximately the same place on the stem; the lowest internode reaching a length of

5 centimetres or 2 inches may be chosen, and the diameter should be expressed in millimetres.

It is strength, not stoutness of stem, which is directly related to lodging, and strength does not lend itself so readily to use as a describable character. Labrador[1] and Mendiola[2] have shown that the Philippine varieties, *Ininteu* and *Binicol*, of which in a given field all the culms of the latter were erect while half of the *Ininteu* culms were reclining, showed a corresponding difference in average breaking strength of culm. The method of testing ascribed to Helmick[3] is described by Mendiola as follows:

> The stem was cut to a length of eight centimetres, using the part nearest the root. This piece was placed across an auger hole in a board, the hole being five centimetres in diameter. A small tin bucket . . . was then suspended from the middle point of the piece of stem by means of a hook made from wire about one millimetre in diameter. A stream of shot and sand is poured into the bucket, and stopped automatically when the culm breaks. The combined weight of bucket and contents required to break the culm was taken to represent the breaking strength of the latter.

The figures obtained in this way were 889 grams for *Binicol* and 623 grams for *Ininteu.* Selection for strength seemed to show a very remarkable increase in the next generation.

It is the actual lodging rather than any factor inducing it, which is a character of direct interest to the grower, but lodging is very subject to influence by outside conditions. Of these, the grower can control the density of stand and the application of fertilizers, has more or less control of other soil conditions and of water, and can take account of the work of insects and the weight of the crop, but cannot at all control the wind or the clouds. As all of these influence lodging, there can be no accurate comparison of varieties unless they grow

[1] Labrador, A., *Selection for Breaking Strength of Culm in Rice.* Unpublished work of the Philippine College of Agriculture.

[2] Mendiola, N. B., *Methods of [illegible] Crops.* Unpublished.

[3] Helmick, B. C., *Journ. Am. Soc. Agronomy,* 7. (1915), 118.

side by side. Where they are so grown a rough quantitative comparison can be made, as Mendiola and Labrador did it, by counting the erect, reclining, and prostrate culms. For the comparison of varieties grown at different places or times (and the difference in time may be no more than is forced by difference in length of growing season), no attempt at quantitative measurement will really gain anything over the usual statement that a variety lodges badly, or slightly, or not at all. For accurate description and comparison we are therefore driven back to determination of breaking strength or diameter of culm.

The most easily measured character is always most convenient for purposes of description. The simplest, least complicated characters are usually most easily measured, in some kind of definite units. And it is the most absolutely simple characters which are inherited, and are therefore the true varietal characters. Diameter is not merely more conveniently measured than breaking strength; it is also more truly a characteristic of the variety, because it is less complicated internally and less subject to outside influence; while lodging is not merely hard to measure quantitatively, but is a most imperfect varietal characteristic, being very complicated and exceedingly subject to outside influence.

As to the leaves, varieties vary in the number, length, width, stiffness, roughness, colour, characteristic angle, and resistance to attack by diseases and pests. Some of these are very important to the grower, quite aside from their providing means of identifying or describing the varieties. Thus the area of foliage, a composite character made up of number, length, and width, and on occasion also of resistance to the attack of enemies, underlies the capacity to produce an ample crop. And the quickness with which the plant develops an ample area of foliage determines the earliness of a possible good crop. *French* rice can produce a heavier early crop than the other varieties in California, because it runs away from them in its early vegetative develop-

ment. Number, length, and width of leaves may be correlated characters, and all correlated with capacity to produce grain, in that all are expressions of vegetative vigour as a more fundamental character; but different varieties do not manifest this vigour in the same ways. Thus *wataribune* has leaves about three-eighths of an inch wide, while *Honduras* and *Blue Rose* have leaves five-eighths of an inch wide (Chambliss and Jenkins), but *wataribune* is decidedly the most prolific of the three.

Rices with the epidermis coloured throughout, or in the streaks between the strands of mechanical tissue in the leaves so that they appear coloured as a whole, are commoner in Central India, or have received more attention there, than elsewhere. They may be pink, red, purplish, or nearly black. Where fields are infested with wild rice, Roy [1] recommends planting a coloured variety so that the weed may be conspicuous and easily rogued out; and Graham [2] cites Mookerjee as having made a similar recommendation. Of the parts of the leaf, the sheath and ligule show distinctive colouring more often than does the blade.

The boot leaf or flag, the last leaf formed, the sheath of which is inflated by the panicle while the latter is "in the boot," differs in development from variety to variety, independent of differences in the other leaves. Its blade may or may not exceed the mature panicle in height; it rarely exceeds the next older leaf.

The ligules present distinctive characters in colour, shape, and size. As a rule, if not white, they agree with the sheath in colour, except that the margins at least are likely to be more highly coloured; but Graham cites *Parewa*, grown in Raipur, as a variety with colourless sheath and coloured ligule, and says that there are others. In size the Japanese varieties grown in the United States are alike in having ligules about half an

[1] Roy, Sudhir Chandra, "Preliminary Classification of the Wild Rices of the Central Provinces and Berar," *Agric. Journ. India*, 18. (1921), 365.

[2] Graham, R. J. D., "Preliminary Note on the Classification of Rice in the Central Provinces," *Mem. Dept. Agric. India*, Bot. Series, 6. (1913), No. 7.

inch long, while varieties of other origin usually have them considerably longer. They may be straight or curved around the stem, broad or narrow, and stiff or very thin. At the base of the ligule is the auricle, a hairy, collar-like outgrowth, which may be distinctive in colour, thickness, and size; it is persistent in *wataribune* and *Bertone*, but deciduous in *Shinriki* and *Honduras*.

All of the characters of varieties so far mentioned are purely vegetative. Some have and some have not a direct industrial importance, but all are useful for the recognition of varieties. And the list does not pretend to be exhaustive. Octubre, in preparing a thesis of which the manuscript seems to have been lost at the Philippine College of Agriculture, made cultures from seed of sixty-six named varieties of Pangasinan rice, and found that without exception they could be recognized by vegetative characters alone.

Construing reproductive characters as only those shown by the grain, the characters of the panicle are intermediate between vegetative and reproductive. The panicle is borne by the peduncle, or upper end of the stem. The line between peduncle and rachis is marked by a ring of hairs; aside from the hairs, it may be more or less evident that this point is a node. In some varieties the whole peduncle remains enclosed by the boot; in others it is exserted to an extent which is a varietal character. As a rule, the best rices have it exserted, but not very far. The panicle as a whole may be almost erect, or more or less curved down; most good varieties have it curved so that at maturity the tip is considerably lower than the base. Among the varietal characters of the panicle are the number of nodes bearing fruiting branches, the number of primary branches and their position and length, the extent to which they branch in turn and the length of the secondary branches, the curving of the branches of both orders, the length of the entire panicle, and the number of grains. The most productive rices usually bear many

branches from the lower nodes and have these freely branched in turn. In describing panicles for purposes of comparison it is advisable to work only with the main panicle of the plant, and to be careful to work only with well- (normally) developed specimens; if this care be not taken, other characters besides size will fail to be comparably described.

The ultimate branchlets, bearing the spikelets or grains, are the pedicels. They vary materially in length. Graham (*l.c.*) made a particular study of the upper end of the pedicel, or facet, where it is enlarged, and the grain is jointed into it. This enlargement is oblique, one side being higher than the other. Varieties with the facet greatly enlarged, so as to give the appearance of an extra pair of glumes, have been described as *Oryza coarctata*. Graham distinguishes the types of facet as ordinary, membraneous, and ciliate. In the ordinary type the facets are cup-like, the rim sometimes being thickened. In the membraneous type the margin is flanged, with an expanded, membraneous lip. Those of the ciliate type have short, erect hairs on the margins. The characters of the facet are of especial interest, because they will probably be found to be related to tightness of grain. If the grain is too loose there is much loss by shattering, and if it is too tight threshing is difficult and incomplete.

Coming to the grain, Graham describes two very aberrant groups, each with two known varieties. One of these has the spikelets clustered in groups of two to seven, instead of borne singly as in ordinary rice. The other has two or more kernels inside each spikelet; this form has been named by Prain *Oryza sativa*, var. *plena*.

The two glumes are usually small and inconspicuous, being either of the same colour as the palea and lemma, or more nearly white and shiny. Graham lists three Indian varieties with pale outer glumes and black palea and lemma, and three others with dark outer and pale inner glumes. He also lists three varieties from Chanda, having glumes as long as the lemma or longer, giving the

grain a peculiar winged appearance. Kikkawa reports such rice also in China and Japan (and South America !), and says that it is inferior in quality, but supposed to be notably resistant to the wind.

The rachilla or stem of the grain is bent between the glumes and the base of the lemma; according to the form thus given and the extent to which the upper end is thickened, Graham distinguished comma-shaped and elbow-shaped rachillae, and states that varieties can be distinguished by these characters.

The lemma and palea compose the hull, and are practically the grain as one sees it before hulling, as together they determine its size, shape, and colour, and other superficial characteristics. Varieties differ in the prominence of the ridges and in the hairiness, but the degrees of difference are not easily described, and the kernel provides a better place to use the ridges or ribs as a characteristic. The colour of the hull is usually related to that of other structures—leaf-sheath, nodes, ligule, stigma, and kernel; but these associations are not constant, the commonest exception being the occurrence of straw-coloured hulls of varieties with the kernel and some other parts coloured. The colour varies from the common straw-colour in one direction to silvery, and in another through red to black. Many varieties have the tips or whole upper ends coloured, while the middle and lower parts are colourless. In some cases the ribs are colourless, but the grooves between them are coloured. Some or all of the ribs project as small protuberances at the apex; the number, size, and colour of these are varietal characteristics, but the colour is sometimes lost as the grain matures.

If an awn is present, it is borne by the lemma. It is a very important hereditary character, in spite of the fact that the measure and constancy of its development are subject to outside influence, at least by the water supply. Of 974 Philippine varieties described as to the presence of awns, they are present on 203 out of 563 lowland varieties and on only 11 out of 411 upland

varieties. It is probable that not a few of the upland rices described as awnless would develop awns if grown in deep water. Awns may be long or short, more or less rough, and present on all grains or only on the more apical ones. In colour they are usually like the hull, but there are varieties with straw-coloured hull and shiny-white, red, or black awns.

Awned rices are regarded with disfavour in most but not all lands. Where harvest is by hand, awned rice is harder and less agreeable to handle. A given bulk of rough awned rice also weighs less and contains less clean rice than the same bulk of awnless rice; this difference may amount to 15 or 20 per cent and involve an appreciable added expense in handling. However, awns are appreciated in India as protection from pigs, and in the Philippines because they keep off the rice birds; they guard the grain against some insects or are associated with other hull characters which do provide such protection; and even rats will let awned rice alone and destroy the awnless. Moreover, awns seem at least sometimes to be associated with general vigour, perhaps in that they were a character of the ancestral wild rice, and the breeder who would get rid of them might conceivably do this through the elimination of vigour. It is hardly questionable that as a general average awned rices are heavier producers than awnless varieties.

Hulls vary in thickness and the grain varies in shape, and in both of these ways the hulls make up a varying proportion of the grain. This finds expression in the milling results, showing a general range from 70 per cent to 90 per cent of the weight of the rough rice as the total of milled rice, bran, and polish. The percentage of hull ran from 15·8 to 23·0 in 50 varieties tested at Buitenzorg by v. d. Stok. As the hull is a total waste, a low per cent of it is a most valuable characteristic of any rough rice variety. For obvious reasons it is a general rule that the rounder the grain and kernel, the smaller the proportion of hull, very slender rices and very

flat rices being wasteful in this respect, as well as because the kernels are more likely to be broken in the mill. For similar reasons, large grains have a smaller proportion of hull than do small grains.

Size of grain is a very familiar varietal character; but it corresponds roughly to size of kernel, the two naturally varying together. As there is no object in treating size of both grain and kernel, and the kernel is the easier to measure accurately, the latter is usually chosen for the expression of this character.

As the general shape is a function of the three diameters, the same consideration might seem to apply with equal force to the shape as to the size. But in this case there are details, such as pointedness and obliquity, in which the correspondence of grain and kernel is not so complete; and the hull offers the further advantage of having two parts, lemma and palea, for comparison. As there is no sharp line of division between any two classes defined by shape, but every inter-grade exists between the roundest and the most slender, the number of different shapes it is worth while to try to recognize is a matter of judgement. In the United States it is usual to group all rices in three classes—round, medium, and long. Kikkawa [1] has tried to distinguish six. Graham, working with 670 varieties of the Central Provinces of India, recognized five groups, taking the shape of lemma and palea into account together:

I. Lemma and palea slightly convex.
II. Lemma and palea convex.
III. Lemma and palea very convex.
IV. Lemma slightly convex, palea convex.
V. Lemma slightly convex or straight, palea straight or slightly concave.

Roughly, a slightly convex lemma is four times as long as broad; a convex one, three times; very convex, less

[1] Kikkawa, S., "On the Classification of Cultivated Rices," *Journ. Coll. Agric. Tokyo*, 3. (1912), 11-108.

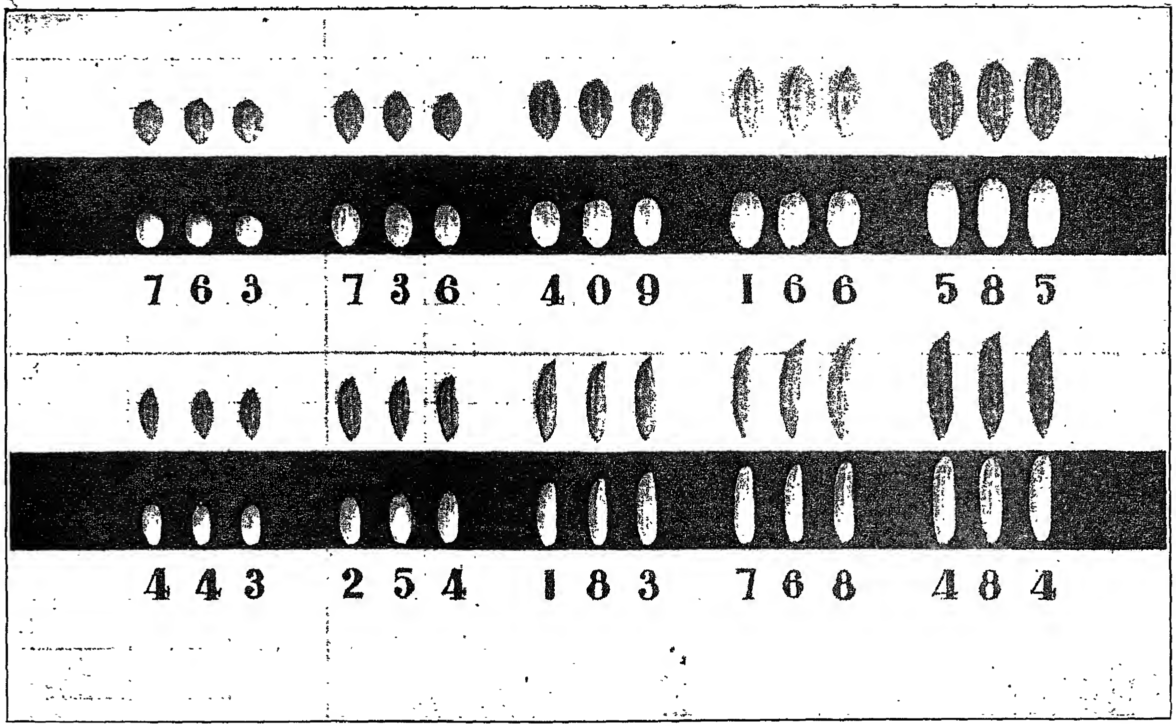
than three times: a slightly convex palea is five times as long as broad; a convex one, four times; very convex, less than four times. The first of these groups, comprising rices with long to medium grains, is by far the commonest or largest, and the fifth, with bent or twisted grains, is rare.

The stigmas of rice are usually white, but may be red or black. These colours are quite constantly associated with similar colours of the sheaths or nodes, and therefore do not need to be used as varietal characters by themselves.

As to the kernel, the ultimately important part of rice and the part most certainly available for study and comparison, varieties differ in size, shape, colour, texture, and composition. Size can be expressed in lineal units or by weight. Both should be used, but published data rarely include the weight of the kernel. While length is easily measured, and is stated in descriptions as often as is any character, its use for purposes of classification of varieties is limited by the fact that rices as a whole do not fall naturally into separable groups. The difference in length between *wataribune* and *Blue Rose*, 5·5 mm. and 6·6 mm. respectively,[1] is sufficient to distinguish these two varieties very conveniently; for in any pure variety the length is a decidedly constant character. But if all the varieties of rice are under consideration, there will be found no gap of a tenth of a millimetre between kernels 5 mm. and those 9 mm. long. In the United States three groups are recognized: short, less than 6 mm. long; medium, 6 to 7 mm.; and long, 7 mm. or longer. In considering all varieties, there may be added: very short, less than 5 mm.; and very long, more than 8 mm. There is much confusion in the literature because writers have often failed to make it clear whether their measurements refer to the whole grain or to the kernel.

Shape of kernel requires attention, even if it be given

[1] Chambliss and Jenkins, "Some New Varieties of Rice," U.S. Dept. Agr., *Department Bull.*, No. 1127, 1923.



GRAINS AND KERNELS OF PHILIPPINE RICE.

(From Camus: "Rice in the Philippines.")

STOUT GRAINS:—Nos. 763, Quinulantro; 736, Quinamalig; 409, Gui-os I.; 166, Cabonog: 585, Mandogosoc.
SLENDER GRAINS:—Nos. 443, Inanis; 254, Capichola; 183, Cadimaya; 768, Romero I.; 484, Kinanay.

To face page 116.

also to that of the grain or hull; for width is a diagnostic character of economic importance. In speaking of width, it is best to use the word strictly, and refer to the position of the grain and kernel as they grow, not as they lie on the table; the width is then the least of the three dimensions, and the middle one, which may be called width if the word is used without care, is the depth or thickness. A narrow kernel (one with little width), like a slender one (one with little thickness or depth), is likely to mill poorly, having a relatively high proportion of hull, even if it does not break badly.

The prominence of the ribs and grooves on the kernel is characteristic of varieties, even if not directly definable in a sufficiently quantitative way to make it usable in general classification. The less prominent these are, the better the rice for milling purposes. Deeply grooved red grains in white rice are especially objectionable, because a great deal of all the rice must be polished off to secure a product free of red streaks. This character of rice could be expressed best in terms of the percentage of bran and polish in milling, but it would not pay to try to get this figure for any great number of varieties.

Colour of grain is one of the most used characters. The general classification is into white and coloured rices. But the coloured group includes pink, red, purple, and black, in various shades. The colour is almost always superficial, so that it can be milled off, which involves undue waste in milling and results in an unattractive product; for, if there is much red present, its powder gives a tint to the entire product. There is rice, at least in the Philippines (*Pirurutong*), with the endosperm coloured throughout; it is itself glutinous, and is used to give colour to "dulces" made of glutinous rice. Rice with a coloured stigma is likely to have the tip of the grain coloured, a fine brown tip remaining where there was a pink or red stigma. The group of white rices is likewise not uniform, the colour varying through yellow. And in both groups the surface, both

before and after milling, varies from dull to shiny. The embryo is usually but not always of about the same colour as the rest of the kernel. Really white patches of otherwise so-called white grains are peculiarities of texture and composition.

The world's commerce demands white rice. Where rice is not grown, there is no market at all for red rice as such, and the presence of red grains depreciates the price greatly; and in rice-growing lands the general preference is everywhere for white rice. Still, leaving out of consideration here red rice as a weed, there are a great number of recognized varieties of red rice deliberately grown, because of distinctive flavour, high yield, or the belief that they are especially nutritious or health-producing. The presence of red in the milled rice being itself evidence of incomplete milling, this incompleteness may explain the nutritive value of such rice. I know of no analyses, but have seen and heard it stated that red rice is richer in iron and phosphorus. Red varieties are mostly very local, which may partly explain the supposed very large number of varieties in proportion to the small total amount of red rice raised. Even the presence of red grains in white rice is not quite always a commercial disadvantage. They are sometimes demanded by consumers to identify Piedmont rice, and in the Orient likewise are sometimes taken as evidence of the genuineness of particular commercial rices.

Texture and composition are of course not really distinct. As the words are here used, texture applies to such structural characteristics as are manifest without chemical treatment, as hardness and appearance in section. Hardness is measurable, but has not been measured, rice being described merely as hard or soft. This quality finds expression in the appearance of the kernel, before and after cutting. Description of the section of the kernel, cut square across midway between the ends, does away with the need, for purposes of systematic description, of such terms as "white-

bellied," and at the same time provides data for an accurate estimate of the relative hardness. Such a section of most rices, while it is all called white, is in part rather translucent, and in part really white and opaque. The translucent part is sometimes called corneous (horny), sometimes vitreous (glassy) ; corneous describes it well. As the rice dries, it becomes very hard. The white part looks starchy, and is often described as the starchy part ; which is not a good distinctive description because the corneous part may be the more densely stored with starch. Rundles,[1] with 120 varieties of Philippine rice in hand, divided them into four groups by this character : entirely corneous, 16 varieties ; largely corneous, 68 varieties ; slightly corneous, 15 varieties ; and starchy (should be *opaque*), 21 varieties. The first and second groups include the best commercial rices ; they include all grown in the United States. The opaque portion may occupy the middle of the kernel and extend chiefly toward the dorsal side, or it may extend inward from the dorsal side. It is the corneous kernel or part of a kernel which is hard enough to take a good polish in milling. Corneous grains also keep and stand shipment better than the usually softer opaque rices.

There are of course many respects in which varieties differ chemically, even the flavour being one of them ; but the one difference recognized as distinguishing two great groups is in the stickiness when cooked. Rice which forms a sticky mass when so cooked that ordinary rice would have its kernels free is *called* glutinous, though the substances responsible for the behaviour are carbohydrates, more soluble than starch. The so-called glutinous rices form a well-marked group, very rich in varieties. They have a starchy (!) opaque appearance, are soft, compared with the corneous or largely corneous varieties of starchy rice, and as a purely general rule, to which there are many exceptions, are large-grained

[1] Rundles, J. C., "Rice Judging and Study," *Phil. Agric. and Forester*, 3. (1915), 181.

varieties. When boiled, they make a gluey mass, while common rice, properly cooked, remains composed of free, entirely distinct, and reasonably firm grains.

No distinctively glutinous rice is an article of world commerce, and such rices are unknown in most lands. Even as near to the centre of the rice region as the Central Provinces of India, no glutinous variety is cultivated. It is unbelievable that it is really the chief food of any people, in spite of such statements as that of Simmonds (*Tropical Agriculture*, p. 323) that it is the chief food of the Karens and other hill-people. It is, however, a product of very considerable importance, being the characteristic material used in making pastries in the great rice region, and used on a large scale by the Chinese. It is not impossible that its peculiar properties will in the future find a place for it in use elsewhere and in commerce. In all countries where they are known there are glutinous varieties more highly priced than any other rices. The varieties are quite local, wherefore they are very numerous. Of 974 classified Philippine varieties, 144 are glutinous. Corresponding figures for Javanese varieties are 756 and 41.

Those who raise rice for their own or for local consumption know the varieties by their cooking properties and their flavours, and naturally attach the greatest importance to these properties. This explains the cultivation of a great number of varieties which do not seem at all worthy of attention in other respects. But neither of these characters, for obvious reasons, is easily definable or available for the classification of varieties in general.

Turning now to those varietal characters which appear in behaviour, rather than in visible or measurable structure, tightness of grain is one so known, although study may remove it from this class. Varieties vary greatly in this respect, ranging from those with grain so loose that there is a material loss in spite of careful hand-harvesting, to the other extreme in which it is so tight that it is not possible to thresh it all out,

at any rate without breaking a large part of it. *Suehiro* is of the latter type; setting their concaves as close as they dared to, threshers in California have still sometimes found it worth while to re-thresh their straw piles. The original wild rice probably shed its grains freely as they matured. The red rices which are weeds are such because they retain this character. The shedding of grain before or during harvest is called shattering. The only attempt to measure the tendency to shatter quantitatively is reported by Mendiola (*l.c.* MSS.), using a device made by Professor Cuzner, which subjected the heads to a given shock of measured violence, after which the grains broken off were counted. As other publications state at most that the varieties discussed do or do not shatter badly, or that one shatters worse than another, this character cannot yet be used to identify or distinguish varieties in general.

The measure of tightness of grain which is desirable depends upon the harvesting methods in use. Where binders are used, the grain must be much tighter than is necessary where the grain is cut by hand. And where threshing machines are used, the grain may be tight in a measure which would be very inconvenient where the separation is performed in other ways. The tendency to shatter seems to be subject to modification by the treatment of the ripening grain, but this subject has not been studied. Some varieties, as *Colusa*, become looser as they pass ripeness, while some are tighter when fully ripe than shortly before that time.

Length of the growing season demanded by a variety is a most important character, almost always reported if anything at all is said about the agronomic characters. It ranges from a scant two months to a full ten months. Under fixed conditions, this character is so fixed that differences of less than a week will be found constant from year to year. And differences as little as this are important in some lands to ensure the crops against danger from weather, and in others to provide a succession of ripening crops, instead of having ripe at

one moment greater areas than can be attended to. Although thus constant, under fixed conditions, and simply stated, as such a number of days, this is really no simple character of the plant. It is possible that there is an inherited tendency to a given length of life. More probably, there is an inherited ability to develop at a given rate, varying with outside conditions. It has already been shown that *French* and certain Japanese varieties germinate and grow well at temperatures at which *Honduras* and certain Philippine rices will not grow at all. While such temperatures prevail the former varieties get a head start, which naturally results in their reaching maturity sooner. Where the prevailing temperature favours the tropical rices, the respective periods may be reversed. Chambliss and Jenkins (*l.c.*) rate *Honduras* as two weeks earlier than *wataribune* in Louisiana; but in California the former is so much later that, after a number of attempts, its cultivation has been abandoned. But, since *wataribune* planted in California, April 1 and May 15, ripens at nearly the same time (although with different yield), it is clear that a statement of number of days from planting to harvest means but little without further explanation of the environmental conditions.

In Spain and Italy particular attention has been given to one of these environmental factors, heat. Attempts have been made to fix a minimum average temperature for growing a satisfactory crop—19° C., according to Selmi, a figure certainly too low for typical tropical rices. Another attempt has been to find a total of heat units necessary to ripen a crop, this figure being obtained by adding the daily temperatures. Thus Comas[1] cites data by Via, to the effect that rice at Amposta, Spain, variety not stated, matured when the sum reached in this manner amounted to 3607° C. Either average temperature, or this total of temperatures may, within limits, be a varietal character. But only within limits; because, to use an extreme illustra-

[1] *Actes du Congrès Internat. de Riziculture à Valence*, 1914, p. 303.

tion, there are rices which practically will not grow at all at 19° C., and no summation of degrees at or below this temperature would ever produce a crop of such varieties. Comparing varieties grown side by side, or, with a great deal more time, comparing averages of varieties in a rice area over which average conditions are uniform, these heat constants may serve to characterize varieties in a very useful manner. But they cannot be used as independent characteristics of varieties grown under materially different conditions.

Moreover, heat is only one of the factors determining or influencing the length of the plant's life. Light, water, and soil, particularly the content of available ammonium, are certainly other factors.

Independent of length of life cycle, as a genetic characteristic, but easily subject to confusion with it, is probably an inherited tendency to respond to certain outside conditions by flowering and by fruiting. Such a response can, of course, be made only by plants prepared to make it by a measure of previous development; but, subject to this limitation, there is reason to believe that the flowering and fruiting of plants are regulated quite exactly as to their time by outside conditions. It is this kind of regulation which is responsible for the simultaneous flowering of certain orchids common in coco-nut groves, and of the trees of a kind in tropical forests. The United States Department of Agriculture has found length of day to be a very important regulator of the reproductive activities of a number of crops, and has shown that difference in response to this stimulus causes differences in the date of crops of different varieties. This has been proved true of enough other plants to make it extremely probable that varieties of rice differ in their response to the length of day, as it shortens in July, August, and September; and that this varietal character, once well understood, will be of great practical importance both in the choice of varieties and in their treatment. Among other things, it may be expected to explain the facts that earliness of planting

in California has a marked influence on the yield, but very little effect on the date of maturity, and that the apparent delay in development in early summer, caused by the use of deep water to drown weeds, does not result in an appreciable delay of the harvest.

The most generally important of all the characteristics of rice varieties is the yield. This character is hereditary, in the sense that with the best possible treatment, or with any definite practical treatment, each variety will produce a crop characteristic in amount, as well as in other respects, of that variety. As every grower has learned to his cost, this amount is subject to decrease by variation in the treatment or environment. But, assuming the best treatment economically practicable, no feasible change will increase the yield. It therefore particularly behooves every grower to endeavour to plant that variety which has the greatest hereditary yielding power under the best treatment he is able to give it, or one which fully compensates for a lower yield by superior quality or cheaper or more certain production.

While yield is the most important of the agronomic characters of rice varieties, and usually the chief basis of the grower's selection among the varieties available for his use, it is not of primary value in the systematic description of varieties. This is partly because there is no sharp line between varieties in this respect, but chiefly because this is the most complex of all characteristics, and therefore the most subject to influence by the conditions under which the crop is raised. The case is not merely that rices grown at different places or by different treatment are not fairly to be compared in this respect. The fact just brought out with regard to length of growing season, that two rices grown side by side in different places may not show the same relative behaviour, is much more generally and conspicuously true with regard to yield. For in yield all of the activities of the plant, and all of its responses to all outside conditions, find their combined expression.

Java is famous as a uniform land with uniform climate. But the Dutch rice experts have seen the strains most remarkably productive at Buitenzorg fail to surpass local varieties in other places so often that they would not think of advocating the planting of any variety or strain on a considerable scale before its value has been definitely established in the particular locality under consideration. The Italian experiment station has, then, no confidence at all that the most productive Japanese, Spanish, or American variety will yield well in Italy, and tests it for a number of years before venturing to distribute seed to growers.

In much that has just been stated there is the assumption, which is a fact, that the responses to a variety of outside conditions are important characteristics of the different varieties of rice. The power to thrive at temperatures below 20° C. determines, for example, what varieties may be grown in California, Italy, and Korea, and Turkestan rices will probably be found to have the same power, as also the varieties grown at considerable altitudes in the Tropics. In the Philippines a lowland pure strain yielding very heavily was distributed in the mountains of Northern Luzon and would do nothing there; and another such strain sent to the cool lake region of Mindanao seemed able to live indefinitely, but never reached the reproductive stage.

The most interesting and generally important of the adaptations of rice varieties to the environment are those to varying amounts of water. On this basis the varieties are divided into great classes, upland and lowland or paddy or irrigated. The groups of varieties are not sharply separated in nature, being blended by many varieties which thrive with or without irrigation, but the division is practical by definition and conforms to agronomic practice. Practically all the rice of commerce is irrigated, as is also by far the larger part of the rice locally consumed by all the great rice-producing countries. However, upland rice, too, is a

very important product. Irrigated rice is in general the more productive, which is natural both because rice is naturally a plant of wet places and because it is less exposed to the vicissitudes of the weather. The respective advantages of the two systems of culture will be explained more fully in the chapter on rice in the Philippines. Most upland varieties are local, and the number is therefore great in proportion to the amount of such rice produced.

Treating as upland all rices able to thrive without irrigation, even those which are more productive if irrigated, the varieties still included in the lowland group differ in the amount of water they require or can endure. Some thrive best if the water is drawn off for a time, once or oftener, while others require prolonged or constant irrigation. At the extreme of those enduring deep and prolonged irrigation are the Cambodian floating rices, which endure water more than four metres deep.

It was formerly supposed that all rice required a moist atmosphere for its proper development, and that the more humid the air the better, but this idea has been thoroughly exploded. It is more probable that all rice, if supplied with liquid water in the amount and manner appropriate to the several varieties, thrives best if the air is dry enough to keep the transpiration active; rice certainly thrives in the very dry air of the California summer.

Regarding the adaptations of varieties to other factors of the environment, our present information consists of scattered items. In some places particular varieties are considered appropriate to particular types of soil, as light or heavy. In California, *Colusa* is often planted on new land, but rarely on land previously in rice, on which its yield suffers more than that of other varieties. Varieties differ in their demand for and response to fertilizers. *Bomba,* in Spain, is fertilized less heavily than are *amonquili* and *Benlloch.* In Java the ratio of weight of grain and straw is said to be influenced by fertilization in some varieties, but not

in others. One or more Philippine varieties, and also some in India, can endure strongly brackish water, which fits them for irrigation by the play of the tide in estuaries. The Lanao Moros have a variety especially adapted to land previously in cogon grass, where other rices thrive very poorly. The known fitness of a great many varieties to quite local conditions must rest on characters of this kind, but we know nothing about what factors of the environment are responsible in most of these instances.

As most of the named varieties actually are, purity of strain is one of their important characters, although in a stricter use of the word a variety must be presumed to be one single strain. Mixture is a more or less serious demerit. The most conspicuous one is the presence of red rice in white varieties, and has already been discussed. *Early wataribune* in California is a mixture in which a small fraction matures before the dominant strain and a larger fraction considerably later; there is no time of harvest at which some of the grain will not be immature or over-ripe. In practically all mixtures some of the strains are poor yielders, so that the crop is smaller than would be produced by a pure strain of the best yielding form. From such mixed varieties it is therefore always possible to select a pure strain of superior yielding capacity, at least locally. But this advantage may be purely local, and may even be undone by the variation in weather from year to year. To obviate the danger of failure due to the extreme adaptation of pure rice varieties to very narrowly limited sets of environmental conditions, the Department of Agriculture, etc., of the Dutch Indies[1] hit upon the expedient of deliberately mixing seed of varieties of similar appearance and time of ripening, thereby producing what would seem like a homogeneous variety, but would probably be less local in its fitness.

It will be observed that some of the characters of varieties are important in determining the variety to be

[1] *Jaarboek*, 1915, p. 138.

chosen for planting; some are important in deciding the treatment necessary to secure the best crop; and some have no known use aside from the recognition of the variety. The accurate and positive recognition of varieties is of real value. And as rices become better understood various characters may be found to have further significance. A very perfect knowledge of varieties cannot be otherwise than helpful, and most descriptions convey a very imperfect idea. If substantially the points in the following outline are covered in future descriptions of varieties, it will be possible to recognize or identify them with a confidence impossible by the use of most hitherto published descriptions, and, in testing new, strange, or imported varieties, to do this much more competently.

Outline of Description

General data:

- Name of variety.
- Locality.
- Character and preparation of soil.
- Dates of planting, transplanting, flowering, and fruiting.
- Amount of seed per unit of area, or
  - Distance between plants.
- Uniformity of behaviour and crop.

Morphological data:

Roots:

- Coarse or fine, proportion of each.
- Abundance of root hairs (?).
- Origin (all from base of stem, or some from higher up).
- Distance reached, horizontally and in depth.

Stems:

- Number of culms.
- Height of main and other culms (to tip of panicle).
- Number of basal internodes.
- Number of elongated internodes (3 cm. or more).
- Diameter of lowest elongated internode.
- Breaking strength of same.
- Colour of internodes.
- Colour of nodes.

Leaves :
- Colour of sheaths, including nodal points.
- Length of blades.
- Width of blades.
- Position (angle) of blades.
- Texture of blades (thick or thin, stiff or not so).
- Surface of blades (smooth, rough, or catchy).
- Colour of blades.
- Peculiarities of boot leaf.
- Ligule :
  - Length, shape, colour, texture, and margin.
- Auricle :
  - Prominence, persistency, and colour.

Peduncle (exserted or not, and how far) :
- Prominence of node at apex.

Panicle :
- Length.
- Number of nodes of rachis.
- Number and location of primary branches.
- Number and location of secondary branches.
- Curving of rachis and branches.
- Number of spikelets :
  - Number of abortive spikelets (without kernels).
- Differences between main and other panicles.
- Length of pedicels.
- Facet—size, shape, and margin.

Grains :
- Glumes—colour, size, margin.
- Rachilla—form.
- Shape (define directly or by shape of lemma and palet).
- Length.
- Weight.
- Hairiness.
- Colour.
- Teeth at apex—number, prominence, colour.
- Awn—length, colour, roughness, persistency, constancy.

Kernels :
- Size (length, width, and thickness).
- Weight.
- Shape.
- Colour.

Prominence of ribs.
Embryo—size, position, colour.
Description of cross-section.

Analytical data :
- Reaction to iodine.
- Percentage of starch.
- Percentage of water.

Keeping quality.

Cooking quality :
- Proportion of water taken up.
- Hardness, flavour, and odour.

Agronomic and physiological data :

Relation to heat :
- Minimum temperature for germination and growth.
- Temperature required for vigorous growth.

Relation to water :
- Upland or lowland.
- Amount of rainfall or irrigation water required.
- Regularity of rainfall or irrigation necessary.
- Effect of too much or too little water.

Length of day at flowering and maturity.
Fertilizers used.
Liability to attack by diseases and pests.
Liability to injury by weeds.
Tendency to lodge.
Tendency to shatter.
Yield.
Additional notes.

Milling data :

Cup weight (weight of a given volume of grain).
Weight of same volume of head rice.

Mill return :
- Head rice per cent.
  - Grade.
- Screenings per cent.
- Brewer's per cent.
- Flour and polish per cent.
- Bran per cent.
- Loss in milling per cent.

Market data.

The Varieties of Rice.—The number of distinct varieties reaches a number of thousands, surely far more than are known of any other crop, and probably more than of all other cereals combined. There is no land in the tropical Orient, even Java, in which the number can be stated with any confidence. In Java, Indo-China, and Japan the estimates are more or less 1000 each. In the Philippines some 3500 varietal names are known; and from the tests of 1282 supposed varieties by the Government from 1909 to 1919, showing 991 to be distinguishable when grown side by side, it may be presumed that more than 2000 are really different. In India about 8000 varietal names have been recorded, and there is no responsible estimate of the number that are distinct. The estimate for Ceylon is only 200. The number of Chinese varieties is not guessed at. Even where rice is not native, the varieties are not few. Carolina rice, supposed to be originally a Madagascar country variety, keeps its name as two varieties, *White Carolina* and *Golden Carolina*, but as one parent of hybrids is giving rise to new varieties in Java, and may be a parent, by way of Mexico and Honduras, of the several varieties known as a group as Honduras rices.

Supposedly new varieties are being discovered or produced every year, and it is only within the last few years that the subject is being watched closely enough for us to be likely to have authentic records of their origin or parentage. Thus I have from France, from Vilmorin-Andrieux et Cie., what was received as Piedmont rice, variety *Française*, which I call *French*, containing at least a dozen strains distinguishable in the field. I am told positively by certain Japanese, whom I have found to know rice intimately, that this is a Japanese variety, including the off-strains, and that they have no doubt at all that it was taken at some time from Japan to Europe; but it would probably be quite impossible now to trace it back to Japan. Lists of Italian varieties include *French, small French*, and *early French*.

Practically all varieties, except those recent ones developed from line cultures, "pedigreed," are mixtures of this kind. These mixtures, country varieties, appropriately called "populaties" by the Dutch, present an almost insuperable obstacle to the complete and accurate description and classification of the host of varieties; but at the same time provide unlimited material for the breeder, and an opportunity for improvement in any desired direction by careful selection.

Aside from the fascination of large numbers, and from the difficulty of classifying them, and from the advantage of ample material for selection and adaptation, the great number of varieties has several other points of interest. It has been construed, with some reason, as evidence of great antiquity of cultivation. And the remarkable wealth of varieties in South-Eastern Asia is regarded as evidence that rice cultivation began there, for which belief there is sufficient other ground. Just as the vast number of species of insects is associated with the fact that the single kinds thrive only under very narrowly limited sets of conditions to which they are very perfectly adapted, so is the remarkable number of rice varieties related to a similarly perfect but restricted adaptation to particular combinations of climatic conditions and treatment, and to particular demands by users as well as by growers.

Clearly it is this fitness of the varieties to particular places and uses which explains their perpetuation and their receiving names as varieties and groups of varieties. However, the culture of varieties has gone to an unfortunate extreme in that there surely are countless varieties without which the rice industry would be better off. The number of varieties cultivated, each with its own characteristic responses to varied methods of treatment, creates a constant doubt, in the present stage of the study of rice culture, as to how far any supposed improvement in practice may be applicable, and makes it physically impossible, with the materials and resources of any experiment station, to test this

question completely. If this proposition were merely that we are swamped by a wealth of material, it would be a desirable sort of temporary difficulty. But beyond this, the real difficulty is that an altogether useless number of varieties conceals the valuable ones and impedes their study, and still more seriously prevents the application of the results of such study.

However the number of varieties and the fact that most of them are mixtures may interfere with the identification, description, and classification of varieties, this work must be done. Its accomplishment, with only reasonable completeness, will provide a much-needed foundation for the most effective improvement of the rice industry of every country. Such knowledge of the varieties will serve this end by bringing the better local varieties into more exclusive use and eliminating the superfluous varieties; by making the cultural treatment more appropriate to the particular varieties; by letting varieties be introduced from country to country and from place to place with increased likelihood that the introduction will be worth the effort of the test; and by making the results of investigation at the scattered centres of study usable elsewhere in a measure not at present practicable. The chief obstacle in the way of the use of the large amount of scattered information we already have regarding varieties is the absence of any generally recognized scheme of classification of the varieties. Without classification of the varieties, arrangement and co-ordination of the information is impossible, and the greater the amount of scattered information the more deeply it buries itself.

The need of a classification of varieties has been felt long and generally. The first resolution presented to the Rice Congress at Valencia (*l.c.* p. 88) by Mr. Montesoro, director of the school of rice culture at Sueca and reporter to the first section of the Congress, was one urging the "formation of a real botanical classification of the varieties of cultivated rice." The discussion

brought out a belief that this proposition was too ambitious, and the resolution adopted was:

That there be made in all countries a botanical study of the varieties of cultivated rice, seeking a provisional classification, based on the characters which may be considered fixed. That when one or other of these characters shall be recognized, the Stations notify those of the other countries busy with studies of this kind, for the purpose of attaining uniformity of method.

The difficulties in the way of a general classification are:

First.—The great number of varieties.

Second.—The fact that very few of the varieties are completely or sufficiently described.

Third.—The fact that some of the characters of the varieties change with the environment, so that a description perfect in one place may be incorrect elsewhere.

Fourth.—The fact that the two characters of greatest agronomic importance, yield and length of season, are very subject to change with climate and treatment, and therefore especially hard to use in a comparison of varieties in different places.

Fifth.—The fact that but few of the named varieties are homogeneous, the most of them being mixtures.

Some of these difficulties can be removed, because they are due to ignorance. The named varieties can everywhere, with sufficient effort, which is not impracticable in the case of those grown on any considerable scale, be described with sufficient completeness; the form just given should facilitate this work. With greater effort and more direct profit those of established importance can be bred as pure lines and described as such. These studies will eliminate the second and fifth obstacles to a clear understanding of the subject, and the third will then be on the way to being cleared up. When the varieties which are anywhere of considerable importance are clearly known, the many others which are at most of possible value can be left out of account, subject to study as occasion may permit in the lands

where they occur. A general classification of the known important varieties of the whole world will then be possible, leaving, for use near the end of the scheme or key, those relatively indefinable characters best expressed by a comparison of varieties (as that one cooks harder or is more savoury than another), and those other characters, however important, which vary in their expression with the environment. Such a classification will be substantially that advocated by Montesoro.

In undertaking to set up a plan of classification, three chief principles should be observed: the objects of classification should be kept in mind; it should be as easy as possible to use; and it should be natural if this is possible. A natural classification is one which expresses the true genetic relationships of the things classified. All botanical classifications aim to do this; while they fail essentially so to do, they are regarded as artificial and tentative. An artificial classification may be more easily used than a natural one, but it can have no other merit. For a natural classification is much more than a botanist's ideal. By grouping together the varieties which are really related, it groups those which inherit a tendency to behave alike; and behaviour sums up those characters which most concern us. If we had a natural classification of the varieties of rice, we could forecast with a large measure of probability the extent to which varieties would respond alike to cultural treatment, would know which varieties could be imported to any place with expectation of profit, and could predict the effects and effectiveness of hybridization.

Unfortunately, our present knowledge of varieties is insufficient to permit any near approach to a natural classification. After excluding a few small and sharply marked groups, we know no natural grouping of the remaining great number. Even the two groups of wild and cultivated varieties are probably not entirely natural, but are nearly enough so so that the wild ones may be set aside together. The separation of white and coloured rices is probably next in the order of naturalness. The

varieties with partial inheritance of colour (in stigma, hull, etc.) may compose natural groups. But beyond colour, we do not know whether the groupings based on need of submergence, content of "gluten," presence of awns, length of glumes, or some other character are most natural. In the present state of our ignorance, the most natural grouping we could make would be along geographical lines; for any Japanese variety is far more likely to be related to any other Japanese variety, except as its characteristics make this seem distinctly unlikely, than to any Javanese variety. The same argument holds true, with diminishing force, as between Philippine and Siamese, and between Luzon and Mindanao varieties. The rice men of temperate lands take advantage of this fact, even if unconsciously, when, having good results with Japanese varieties, they look chiefly to Japan for additional varieties to test. When it comes down to the numerous very local varieties, geography probably furnishes the best guide to relationship that we will find. But it cannot be used to distinguish the great groups, both because such use would defeat the purposes of classification, and because it would not be natural. For the origin of many of the most important varieties is unknown. And in the Orient, the source of all varieties, migration, commerce, and conquest have mixed the rices of different lands. It can hardly be doubted that rice varieties came to Luzon with Sanskrit words and Chinese textiles, and to Mindanao with Islam.

The principle of convenience has application to a key to varieties rather than to their classification. A key is most convenient if the characters on which it is based are easily recognized and clearly defined. It may disregard naturalness for the sake of convenience; and it would not lose in usefulness if the varieties identified by its means were arranged naturally, and regardless of the key. At present a key is all that we can make; but we may hope to approach a natural arrangement in the not distant future.

The ultimate purpose of the effort of making a classification is the improvement of rice culture. It will serve this purpose the better the more natural it is. But it can serve it directly, and more or less independently of its naturalness. For this reason, while we are content to try to make a key, or the beginning of one, the more important agronomic characters should have a prominent place in it, although they would be excluded if convenience alone were considered. A purely artificial key might probably exhaust the visible characters of the grain and kernel before touching such distinctions as upland and lowland, or glutinous and non-glutinous; but the latter are of such outstanding industrial importance, of such primary concern to men interested in growing and selling rice, as well as probably so natural, that the practicality of a key depends upon their having an early place in it. Tightness of grain is important agronomically and is probably characteristic of one or more very natural groups, but is too undefined to be usable in a key. Short or long growing seasons characterize single varieties or small groups, which have been developed independently in many places.

There have been a number of attempts to classify varieties by grain characters alone. Of these it will suffice to present that of Devaux, quoted with approval by Montesoro:

BEARDED AND LONG-GRAINED.—1. Piedmont rice (*Oryza sativa pubescens*). 2. Common rice (*O. sativa communissima*). 3. Red-bearded rice (*O. sativa rufibarbis*). 4. Winged rice (*O. sativa marginata*). 5. Long rice (*O. sativa elongata*). 6. Early rice (*O. sativa praecox*). 7. Early Chinese rice (*O. sativa imperialis*) 8. Long-lived rice (*O. sativa subperennis*). 9. Odorous rice (*O. sativa suavis*). 10. Mountain rice (*O. sativa montana*). 11. Glutinous rice (*O. sativa glutinosa*). 12. Black rice (*O. sativa aterrium*). 13. Red rice (*O. sativa rubra*). 14. Dark rice (*O. sativa nigrescens*). 15. Big rice (*O. sativa grossa*). 16. Pink rice (*O. sativa subcolorata*). 17. Yellow rice (*O. sativa lutescens*). 18. Dove-coloured rice (*O. sativa columbaria*). 19. Variegated rice (*O. sativa discolour*). 20. Sumatra rice (*O. sativa sumatrensis*).

Awned and Round-grained.—21. Short rice (*O. sativa brevis*). 22. Little rice (*O. sativa minima*). 23. Round rice (*O. sativa globosa*). 24. Japanese rice (*O. sativa japonica*). 25. Granular (millet grain) rice (*O. sativa bullosa*).

Beardless and Round-grained.—26. Millet rice (*O. sativa miliacea*). 27. Sorghum rice (*O. sativa sorghoides*).

Beardless and Long-grained.—28. Smooth rice (*O. sativa denudata*). 29. Dusky rice (*O. sativa sordida*). 30. Coppery rice (*O. sativa cuprea*).

There have been extensive studies of the numerous varieties of Japan, Indo-China, and the Central Provinces of India, and a great deal of information has been published on the varieties of the Philippines, Java, and Burma. And the varieties cultivated in Europe and the United States are mostly described. For obvious reasons, the smaller the number of varieties the more easily and perfectly they are classified.

The following skeleton key for the eventual identification of varieties is only a suggestion which can at least serve as basis for modification, while a workable key is evolved during the next few years. It is so planned as to exclude at first a number of easily recognized small groups or (red kernels) groups of minor importance, and then separate the great groups along the lines of greatest importance or convenience; these are "gluten" content, habitat, size and shape of fruit, and presence or absence of awns.

Skeleton Key to Groups of Rice Varieties

A^1. Plural kernels in the hull.
A^2. Plural spikelets at a point.
A^3. Floating rice.
A^4. Ordinary rice.

B^1. Kernel coloured.
B^2. Kernel straw-coloured to white or yellowish.

C^1. Glumes equalling the spikelet.
C^2. Glumes at least half as long as grain.
C^3. Glumes less than half as long as grain.

D^1. Hull coloured throughout.
D^2. Hull partly coloured.
D^3. Hull " white " or stramineous.

E^1. Sheath coloured.
E^2. Sheath colourless.

F^1. Ligule coloured.
F^2. Ligule colourless.

G^1. Glutinous.
G^2. Non-glutinous—the rices of commerce and of general use.

H^1. Awned.
H^2. Awnless.

I^1. Upland.
I^2. Irrigated.

J^1. Kernel very long—more than 8 mm.
J^2. Kernel long—7·1 to 8 mm.
J^3. Kernel medium—6·1 to 7 mm.
J^4. Kernel short—5·1 to 6 mm.
J^5. Kernel very short—less than 5 mm.

K^1. Lemma and palea slightly convex—slender grains.
K^2. Lemma and palea convex—medium-round grains.
K^3. Lemma and palea very convex—very round grains.
K^4. Lemma slightly convex, palea convex.
K^5. Lemma hardly convex, palea straight or concave.

L^1. Kernel corneous.
L^2. Kernel mostly corneous.
L^3. Kernel slightly corneous.
L^4. Kernel not corneous.

There is not at present full knowledge of enough varieties to make it expedient to try to carry this key further. Especially valuable knowledge will be that of fastness of grain and cup weight of grain and perhaps of head rice. Regarding fastness or tightness, more will be said a little later. Cup weight is determined in the United States by weighing a standard small container, and is read as pounds per bushel. A better standard for general use would be metric—the weight in grams of

a litre, ten times the weight in kilos of one hectolitre. The grain tested for comparison should be thoroughly clean and well filled. To provide perfect comparison, the moisture content would also have to be fixed, but air-dry grain will probably be uniform enough in this respect for practical purposes. Cup weight is a complex character of varieties, depending most upon the presence of awns, but also upon shape and size of grain, and thickness of hull and specific gravity of kernel. In the use of cup weight as a key character, awnless rices will be compared only with awnless, and it may be practicable to dispense with shape of grain as a chief character, and to use shape of kernel as a more subordinate one. Cup weight as a market test tells how well the grain is filled and how much foreign matter, chiefly chaff, is present. The greater the weight, if the rice is dry, the better the grade. But different varieties are not compared; good California Japanese rice cups 44 to 46 pounds.

It will, of course, be understood that the key above is presented in outline only. If it were filled out, everything after "H," for example, would be repeated under H^1 and H^2; and B^1 and B^2 would each occupy many pages. The use of an accepted key will provide a formula for the convenient and concise description of varieties. Using it in this way, all of the rices of world commerce will have a formula beginning A^4 B^2 C^3 D^3 E^2 F^2 G^2; and since they will be alike thus far, this part of it may be omitted when dealing exclusively with the rices of any land outside the Orient. The further formula of *wataribune* is H^1 I^2 J^4 K^2 L^2. A considerable number of varieties have the same formula thus far, but will be distinguishable by formula when the key is more complete. *Butte*, better known as "1564," is one of these, with longer and stouter awns and more evenly distributed hairs on the hull, maturing earlier. The formula of *Honduras* is H^2 I^2 J^2 K^1 L^2; very many varieties having this formula remain to be distinguished by further elaboration of the key. The

true formula of *French* is probably $H^2\ I^1\ J^3\ K^2\ L^2$, but no rice can be treated as upland in California.

Colusa, better known as "1600," is $H^2\ I^2\ J^4\ K^2\ L^2$. According to Novelli,[1] this is practically the same as *originario*, differing at most in being slightly more resistant to lodging and with a slightly denser panicle. The seed obtained by Novelli was presumably a pure strain, wherefore particular interest attaches to his attempt to improve it or adapt it to Italian conditions by selection. The same rice is said to be called *Benlloch* in Spain.

Methods of Improvement.—We have now to conclude this chapter, begun with a statement of the importance of using the best possible available seed, with a discussion of the methods of obtaining rice with improved hereditary qualities.

The first and simplest of these methods is by choosing among existing varieties as they are. Enough has already been said about this as a problem of the individual grower who has a limited geographical range of choice, and may not, in general, do wisely in trying to go beyond it. But each land has the possibility of securing more desirable varieties by testing the varieties favoured in other lands with not too dissimilar growing conditions. This is, of course, the method of first beginnings with rice in new lands, and these first attempts are practically never by Government enterprise. But experimental introduction of plants or seed is properly a function of Government, for a number of reasons. In the first place, the chances of profit from any single importation are small, but if the importation is really successful, the public profits by it; the public may therefore well pay for the numerous failures. For reasons emphasized in the preceding chapter, the importation even of seed is attended by grave risk of injury on a large scale by the importation of diseases or pests; and if importation is in the hands of

[1] *Giorn. di Risic.*, 11. (1921), 182. See also Jones, U.S.D.A., *Dept. Bull.* No. 1155, p. 44.

the Government alone, no infected seed can well get by it.

There are other practical if less cogent reasons for importation by the Government only. To secure the best prospect that the effort of importing and testing will be worth while, the seed to be imported must be chosen wisely, and the tests must be made with a care not likely to be given except at an official experiment station, by workers habituated to making experiments *as such*, regardless of any possible immediate economic return from their efforts. Montesoro [1] is most emphatic in demanding full information regarding varieties to be imported.

> Before importing a variety, it is necessary that we have the following data, to know if it is, or is not, adaptable to our country: name of the variety, name of the country of origin, latitude of the locality, physico-chemical analysis of the soil, kind and amount of fertilizers applied, their analysis, amount of water applied per hectare, its analysis, length of irrigating period, temperature of the water, dominant winds in the rice field, mean number of windy days, maximum and minimum velocity of wind, number of calories the plant has absorbed during its period of vegetation, mean daily temperature, labour applied to the plant during its life; it is only by knowledge of these data from the country of origin that we can really judge if the variety to be introduced is adaptable to our fields.

If all of these data were provided, which probably has never happened, the introduction would still be an experiment. None of this information would have let it be foreseen that *Honduras*, earlier than *wataribune* in Louisiana, could not be grown in California, where *wataribune* is the standard variety.

Nothing of possible interest should be omitted from the written record of the test; in this respect private importations are almost sure to be less instructive than they might be. In the brief history of California rice varieties have been condemned as unsuitable and re-imported by another individual and found valuable, the

[1] *L.c.*, Valencia Rice Congress, p. 84.

different result following different use of water; and in other cases a number of individuals have made futile efforts to introduce the same unsuitable variety. Plant introduction as private enterprise is thus particularly wasteful, not so much because its results are not conclusive as because they are not known.

The change a variety may undergo when grown in a new environment is still rather a dark problem. The general belief is that some sort of acclimatization is necessary before a variety should be judged under such conditions. The superintendent of the Biggs Rice Field Station tells me that four years of observation is necessary before it is safe to let a variety go into farm use, and similar views are held by others whose judgement must be respected. I have had an imported variety very promising in the first year, and reasonably so in the second, show itself worthless in the third, but in this case the degeneration was almost certainly the result of selection of inferior strains by the new environment, and could have been prevented by care on my part. This is essentially the same phenomenon, more sudden in action, as the tendency of red rice to take possession of a field. Except as the environment is selecting among strains in a mixed variety, there is no understood reason for deferring judgement for any long time.

In casting doubt on any such frequency of variation under the influence of the environment as would make it necessary to observe a pure strain for a number of years because such change is likely, I wish explicitly to express the belief that such change is not impossible; in other words, that the acclimatization of a pure strain is not an impossibility. Those who rate de Vries as one of the builders of the foundation of plant breeding seem never to observe the implication of two questions in his *Mutationstheorie*: Are there any variations which the environment does not cause? If there are, what does cause them? The number of varieties and their exact adaptation to particular conditions suggest (but of course

do not prove) that rice may be a plant remarkable for genetic plasticity.

In the alleged degeneration of established varieties we have the same phenomenon in another aspect. As examples, Montesoro states that *amonquili* and *bomba*, after giving good results for a considerable time, have gone out of use because they lost their good qualities. As they were not pure strains, the probable explanation is that inferior strains became dominant in the mixtures, displacing the better ones which had been regarded as typical of the varieties; or it may have been that contamination from without the variety was responsible for the loss of value. Montesoro aptly cites this as a demonstration of the need of records of introduction; if the original country of these rices (regarded in Italy as Spanish rices) were known, they could be reintroduced with the likelihood of having their old value. But Palop Diego (*l.c.* p. 103) attacks the problem of rehabilitation with the material in hand, by detecting in the run-down *amonquili* the original good strain, and breeding it by itself with a prompt and substantial increase of yield.

Loss of immunity to a disease is a different matter. It has already been mentioned that the Italian variety *Bertone* lost its immunity to *brussone* (blast) in the course of years. Other highly prized Italian varieties—*novaresa*, *nostrano*, *francone*, and *ostiglia*[1]—have gone the same course. In these cases the probability is that the rice has suffered no change, but that the fungus causing the disease has, by variation and natural selection of more virulent strains or strains specifically able to infect new hosts, acquired the power to attack new hosts. The coffee rust, *Hemileia*, has done the same thing. Liberian coffee was originally practically immune to its attack and is still so in most lands; but in Java this fungus developed the power a decade or so ago to destroy Liberian coffee, as well as Arabian, which is everywhere subject to it.

[1] Fort, *l.c.*, Valencia Congress, p. 112.

It is of course those lands where there is little rice industry but vast possibility of its development which have most to look for from the importation of varieties from lands where rice is old and established; in South America and Africa the better Oriental varieties should be tested in large number before the same effort applied to local breeding will be likely to be equally effective. In Italy and the United States great numbers of varieties have already been tested, only a small part of the Orient offers varieties likely to prove adaptable, and local breeding has long since proved expedient as a means of improvement; still the importation of additional varieties has not ceased to pay. Even a land like Japan, with a wealth of native varieties and most creditable scientific effort applied to their improvement, may still profit by the return of strains selected and possibly improved during culture elsewhere. A thousand new varieties were imported for test in Bengal in 1914 (Finlow).

The other two methods of increasing the profit of rice-growing by making better seed available are comprised under the head of breeding. Breeding may be defined as the science and practice of improving the hereditary quality of a kind of plant or animal. Working on a basis of the more or less understood laws of inheritance, it employs two general methods—selection always and hybridization sometimes.

Since native varieties are mixtures, there is no clear distinction between selection as between varieties and within varieties, but the discussion of the subject may be restricted effectively to the latter. Varieties may be or may contain mixtures in two senses; they are mechanical mixtures in that the field of a variety contains plants of more than one kind; they may also contain genetic mixtures, plants of mixed heredity, which may themselves not breed true. Among these mixtures selection may be more or less fine and accurate, just as one hunts with shot-gun or rifle, according to his purpose, patience, and skill.

"Roguing" the field by eliminating as completely

as may be possible all plants of undesirable strains, is a kind of selection in a broad sense. It is always worth while if there are any plants which would manifestly be undesirable parents. In practice, it is usually worth the effort of farmers who raise their own seed, for the most undesirable strains in a field of an unrefined variety are usually easy to detect. These individuals may be red, or may be bearded while the field as a whole is beardless, or may differ widely from the field as a whole in time of ripening. The time it takes to remove these from a sufficient area to provide the next season's seed is very well spent in this way. In the course of more scientific breeding, individuals recognized as inferior are always eliminated. Natural selection operates only in this negative manner, as the plants which do not fit conditions die, leaving those which do fit to be the parents of another generation.

Mass selection consists in the selection of a number of plants as parents, and using their seed collectively. The number is usually large, because if but few are used the process does not gain much time over line selection, and results are less certain. There is probably no rice land of importance where some growers do not practise some kind of mass selection.[1] As a studied and elaborated process it has been most carefully developed in Italy and Spain, in both of which countries it has long been the established method of improvement, practised by official institutions and encouraged by them as a private activity. As recommended by Professor Novelli, Director of the Italian station at Vercelli, and Director Montesoro of the Spanish station at Sueca and others, the procedure is essentially as follows :

In advance of the harvest a quantity of heads are selected in the field and removed individually. In this selection care is taken that the heads be uniform, and agree especially in the qualities at which the selection

[1] A typical Oriental method is described from Assam by Mitra in *Agric. Journ. India*, 17. (1922), 241. It consists of going over the stored bundles during the season of little work and choosing the best to be used as seed.

is aimed, being, for instance, well filled, vigorous in all respects and thoroughly healthy, with large, evenly matured grains of good colour. Plants from the margin of the field or with exceptional space within the field, or exceptionally robust for any other reason (as growing on a spot accidentally manured) are avoided. Heads are taken from erect plants only. The selected heads are then tied into small sheaves and thoroughly dried. In official stations and elsewhere if such care is practicable, these heads are subjected to study during the winter and such as are found on close scrutiny to be inferior or divergent are discarded. Cutting off the extremities of the panicles and retaining only the middle parts is considered a further refinement. The remaining material is threshed by hand. Light or otherwise defective seed is then separated as completely as possible, mechanically or by gravity.

The seed so obtained is planted by itself and given all possible care. During the weeding all plants backward in development or aberrant in type are rogued out. At flowering time the field is carefully rogued again. Before the harvest heads are selected from this plot for the repetition of all of this procedure. The remainder of the crop of the plot becomes field seed for the following season. There is thus each year a mass selection of seed to be the grandparents of the crop of the second succeeding season, and a double roguing of the intervening generation. As each field selection of heads after the first is made from a plot which has the benefit of the preceding selections, there should be from year to year a steady, progressive approach to the desired pure type.

In the refinement of *amonquili* already referred to, Palop Diego began with a field selection of twelve or fourteen thousand heads and handled some twenty thousand in a subsequent selection of the progeny. In the course of these operations he decreased the proportion of awned grains and the tendency to lodge, got rid of black stems (which he considered of no moment except as a matter of prejudice), and secured fully filled-out heads. In the hands of another grower, Palop Diego's

seed produced a yield 763 kilos per hectare in excess of that of unselected *amonquili*. Similar work by Cuzzoti Bros.[1] with *originario* is said to have resulted in an increase of specific gravity from 1·11 to 1·22, the weight of 100 grains from 2·97 g. to 3·16 g., to have lowered the number of grains per kilogram from 33,603 to 31,289, increased the germination from 85 per cent to 95 per cent, and reduced the number of foreign grains from 25 per cent to 0·5 per cent.

Under the auspices of the Vercelli station it has been the custom for years to give prizes to the growers most successful in the practice of this kind of selection, and there are several Italian seedsmen who grow rice in this manner for seed exclusively. As an effort by those outside of Government employ to improve the quality of rice this Italian practice is the most successful of which there is any record, and the official encouragement has certainly been well directed. As the practice of the stations themselves it has been satisfactory enough to induce the Valencia Congress, with this procedure before it, to adopt as a resolution "That the same method of selection of seed be adopted in all rice-growing countries." The resolution is good, but the procedure they will ultimately agree upon will not be one of mass selection. The Philippine Bureau of Agriculture adopted such a plan in its first careful work on rice, and practised it on a very large scale for several years and, indeed, with considerable satisfaction; but finally abandoned it completely in favour of line selection.

What is meant by "pure line" selection in rice is the selection of a single parent plant, and the multiplication of its progeny. It is known by a number of terms, as the "Svalöf system," because it became famous as the practice of cereal-breeding at the Swedish co-operative station of that name; "head-to-row" culture; and the source of "pedigreed seed." The last is the most accurate and descriptive term, if accurate records, constituting a "pedigree," are kept. A really pure line

[1] Fort, *l.c.* p 123.

may not exist; for back of the chosen parent of such a line there lies an unknown ancestry, mixed in some more or less remote generation. But in practice a race of rice descended from a single parent, and propagating itself without evident aberration, is deemed pure. According to the absoluteness of its purity, deviation from type, as a result of the recombination of ancestral characters or the outcropping of dormant characters, is unlikely to occur.

In the measure in which such a strain breeds true, improvement in it by further selection is not to be looked for, but it is this freedom from deviation which constitutes the basic merit of such strains. For uniformity is a very valuable character in itself. And the particular characters of such strains are also in practice good, in the nature of the case; because the parent of the strain is selected for these characters. And the farmer who grows such a strain, competently selected and bred, can do so with an assurance of uniformity of performance and crop, impossible with seed having any different history. Although breeding stations may keep up the selection and re-selection in pure lines, the occasion for this is not such as to prevent a farmer from growing a long succession of generations, using his own crop as seed and constantly maintaining a uniform product, without other care or effort than the prevention of physical mixture by seed of other kinds. In the absence of this care, of course, no culture can remain pure. I have bought *caloro* only two generations from the breeder and found it strongly contaminated with *Onzen*, surely as a result of physical mixture. The Javanese export-rice known as *Carolina*, whether as a compliment or because of its source, always maintains its quality at Karang Serang,[1] but, taken thence to Kandanghauer, it lost its merit quite completely in the course of a decade, which was ascribed to soil and climate. But investigation showed that the native growers at Kandanghauer had let their seed become very badly contaminated, while at Karang Serang it

[1] *Jaarboek van het Department van Landbouw*, etc., 1915, p. 126.

was their practice to secure new seed at frequent intervals from a certain Chinese grower who took adequate pains to keep his seed pure. The fact is that not only is it easier to secure practically pure lines of rice than of other cereals, but that such lines are maintained with much less effort, because of the comparative absence of cross-pollination in rice.

Absolutely speaking, no seed reproduces with perfect uniformity. Whether as the result of ancestral genetic mixture, or under the influence of the environment, or of variation independent of both of these, some deviation from type is always to be looked for. Official stations are always ready, as a part of their routine work with their pure lines, to take advantage of these deviations if favourable ones are detected, and to prevent deterioration by the propagation of undesirable deviations.

In pedigree culture the individual plant is the point of departure, the living unit with which the breeder begins. The single head has no hereditary merit of its own. It is true that a single good head has seed enough for the first year's test. And it is often impossible to recognise a single plant because several grow together, always in transplanted rice and often in untransplanted, except when the plants are grown one by one for experimental purposes. But on any one plant the seed in the poorest head has the same hereditary quality as the seed in the best. Because of the emphasis sometimes placed on selection of single heads Mendiola and Unite [1] have tested this question with care, finding that the poorer heads may be inferior to the best ones in average weight of grains as well as in more evident respects, but that all the heads of a plant breed alike. While all the seed may be taken from one head, the selection should be of parent *plants*. If attention is paid to heads alone, these may come from plants which do not tiller freely, or do tiller very unevenly; and such defects may be inherited.

As the heads of a plant are alike for breeding pur-

[1] Unite, "Comparative Tests of Rice Seeds from the Principal and Poorest Culms in Individual Plants," *Phil. Agric.* 10. (1921), 243.

poses, so, of course, are all of the sound grains of a head. The practice of discarding the extremities of the panicle is perhaps an imitation of the same practice in work with maize, which does bear smaller grains near the tip. In the case of rice, varieties may differ in this respect, but at least in very many varieties the weight of the grains is progressively greater as the apex is approached.

In line selection, *all* of the characters to be expected of the resulting strain must appear in the parent plant. It is practicable in mass selection to work for a single character, as yield or colour, and afterward to select, one or more at a time, for earliness, disease-resistance, tightness of grain, erectness, cooking quality, hardness, etc. Thus Palop Diego selected first for yield and freedom from disease and awns, and subsequently eliminated black stems. There would have been very little chance of accomplishing this with a pure strain. The most perfect, completely purposeful selection of parent plants is therefore an indispensable pre-requisite to success in line selection.

Line selection has been practised in recent years in almost all rice countries. In the United States three California varieties, *caloro*, *Colusa* or "1600," and *Butte* or "1564," have originated in this way. In the Gulf States the Federal Office of Cereal Investigations[1] released in 1918 the following pure strains, all selected in 1911:

Name.	Parent Variety.	Origin of Parent.	Date of Importation.
Fortuna	*Pa Chiam*	Formosa	1905
Acadia	*Omachi*	Japan	1910
Delitus	*Bertone*	Italy, *via* France	1904
Tokalon	*Carangiang* (Carangcang ?)	Philippines	1904
Evangeline	..	Guatemala	1904
Vintula	..	Ceylon, *via* British Guiana	..
Salvo	*Djember*	Java	1904

[1] Chambliss, C. E., and Jenkins, J. M., "Some New Varieties of Rice," U.S.D.A., *Dept. Bull.* No. 1127, 1923.

The several popular rices of Honduras and other varieties, bred and placed on the market by Mr. Sol. Wright and called "Wright varieties," are also understood to be pure strains. Among Italian varieties, *Ranghino*, *Nero de Vialone*, and *Jancino*, named after their breeders, *Birmania* (bred by Sanmarco) and *Taitu* (bred by Granono), are believed to be pure lines. These and the Wright varieties are the only known pure lines, privately bred, in commercial use.

In British India official effort has produced an enormous number of pure lines. In Burma,[1] several of these are derived from the native *Ngasein*, and released with distinguishing numbers. In different districts, *Ngasein* 2104, *Ngasein* 8, and *Ngasein* 10—the heaviest yielder—are favourites. *Nyachima* and *Letywezin* have also yielded popular strains. Finlow[2] reports that Hector began work with eighteen in 1910 and with nearly a thousand in 1911. Of these, a pure line of *Indrasaïl*, tested at many places in 1914 and 1915, and yielding five to ten maunds per acre better than competing varieties, was the most satisfactory. Wood[3] reports two *Red Samba* strains, 15·5 per cent and 17·5 per cent better in yield than their mixed source, and another strain fifteen to twenty-one days earlier, without decrease in yield.

Line selection in Java[4] has been prolonged and extensive, and has been widely cited as a model for other countries. As begun by van Breda de Haan and continued by van der Stok, the procedure is in essentials as follows: A large number of good individuals of a variety, say 300, are selected from the trial plots of varieties, with the usual care to avoid choosing indi-

[1] *Trop. Agriculturist*, 54. (1920), 133.

[2] Finlow, R. S., "The Improvement of the Rice Crop in Bengal by Pure Line Selection," *Agric. Journ. India*, 12. (1917), 280.

[3] Wood, R. C., *Report on the Operations of the Dept. Agric. Madras*, 1918, 19.

[4] De Haan, J. van Breda, "Les Expériences d'amélioration du riz par la sélection à Java," *Bull. Écon. de l'Indochine*, 16. (1913), No. 100; Vieillard, G., "Note sur la sélection des riz par la constitution des lignées pures et sur les hybridisations des riz," Valencia Congress, 1914, p. 99. Same paper in *Bull. Inst. Scient. Saigon*, 2. (1920), 29.

viduals superior because of superior location in the field. This number is reduced to a fourth by elimination in the laboratory. The remainder are given individual numbers, and the seed of each is planted in several places in the field, thus avoiding the chance that the seed of any one would happen to be exceptionally well placed. This field of trial cultures and selections at Tjikeumeuh, near Buitenzorg, with the adjoining one devoted to perennial cultures under Cramer's direction, is the most interesting scene of such activity I have ever visited. The harvest from the several plots of the same individual parentage is combined, and the collective crops of the many individual numbers of the same kind are carefully compared and judged. Ten or fifteen may be selected for culture in the next crop, and these are grown on as large a scale as seed and convenience permit. At the end of this year comes the final selection of one or more best strains, for multiplication and eventual release for public use.

Up to 1915, when I visited Java, some twenty pure lines had been fully established in this way, of which three were dropped that year because deemed too subject to injury by *Leptocorisa.* The increase in yielding capacity over the mixed native parent strains was about 20 per cent as an average, and reached 30 per cent at most. *Carolina, papaharan, baok,* and *pandan* were notable for fine flavour; while *Skrivimankoti,* a very heavy yielder, was rated low for cooking, because it took up little water and remained hard. *Baok* was further valued for its resistance to root-rot. *Pandan* showed an increase of weight of seed from 42 mg. in the highest test of the parent mixture, to 45·3 mg. On the whole, *baok* and *pandan* would seem to have been the most satisfactory pure strains, but *laradjawi, klepon, oeproek,* and *wriji* were highly prized. V. Breda de Haan reported a yield of 76 picols per bouw, or 5900 lb. per acre by a selection from *Tanggerang* rice, imported fifty years before from Carolina.

Work with pure lines in Java began in 1908. By

1915 doubts as to its utility were freely entertained, and failure to realize the results anticipated was ascribed to limited adaptability on the part of the pure lines. To remedy this disadvantage, mixtures of two to four similar pure lines the product of which would pass as uniform were tested and distributed, and some improvement seemed to result. But as parent mixtures were not infrequently found more prolific than pure lines selected from them, the constitutional vigour of pure lines was brought into question. There is evidence enough to establish the probability that a genetic mixture will show enhanced vigour, as compared with the average of its component races. But there are no dependable data by which it can be calculated that the increase of vigour is an appreciable factor in field production. In Buitenzorg experiments the result of mixing varieties on fifteen plots was an increase of yield on nine and a decrease on six, which is inconclusive. When the last publication on the subject was made, the principles to be observed in mixing pure lines were being studied at Buitenzorg.

In Indo-China, Carle [1] reports on pure line selections of *Phung-tien* and *Nang-Meo*. The yield of the latter was said to be increased from 2000 kg. per hectare to 4019 kg.—an increase surprising enough to raise doubt as to the validity of the comparison. Statements in previous papers justify the presumption that the comparison is of the native mixture and of pure lines grown at the same time. The uncontrollable fluctuation of yield from season to season is everywhere too great to permit conclusions as to yielding power from comparison of the crops of different seasons. In Java there is each season a check against some standard, *baok* for example, known by its records during a series of years, scattered through the field of trial plots. Other selection work in Cochin-China will be noted in the discussion of rice-growing there.

Pure line selections in the Philippines by the Bureau

[1] *Bull. Agric. de l'Inst. Scient. Saigon*, 2. (1920), 29, 73.

of Agriculture[1] began with a collection of several thousand heads from the 1912 crop of the field of variety tests. These were cut down to 100 each of twelve varieties.. Three of these, *Piniling Daniel*, *Inasimang*, and *Macan I.*, survive among the pedigreed strains now distributed by the Bureau. *Roxas*, *Cruz*, *Apostol*, and *Conner*, all developed in earlier years by mass selection, and the upland variety, *Inantipolo II.*, have since been selected as pure lines and distributed. The procedure of the Bureau in this work has been codified,[2] and differs from that in Java only in the unimportant details of beginning with a smaller quantity of material, and postponing multiplication until after three years of selection by rows; and the head (as distinguished from the plant) still receives undue attention.

At the Philippine College of Agriculture pure line selection began in 1915 with selections of *Iray*, *Binalayan*, *Binangbang*, *Diquit à Bolilising*, *Ganado*, and another variety since discarded. These have been carried forward by Romero, Cabanos, Bernardo, and others; and Professor Mendiola and his assistants have increased the scope of such work until by 1921, ninety-four native varieties were in process of selection to pure strains at one time. Particular attention has been given to such basic problems as range of variability in various respects, and to technique, as in tests of tightness of grain and strength of culm. Increases of yield as high as 50 per cent are claimed for certain upland varieties of which the parent mixtures were considered to yield well; and still higher increases are alleged, but these, as well as claims of marked improvement after several years of selection, are based on comparison of crops in successive seasons.

Pure line selection is understood to have begun in Japan as early as in Java, and to have been practised extensively; but the results obtained there are not known to me.

[1] Jacobson, H. O., "Head-to-the-row Test with Rice," *Phil. Agric. Rev.* 7. (1914), 346.

[2] Camus, J. C., "Rice in the Philippines," *Phil. Agric. Rev.* 14. (1920), 7-86; *Bureau of Agric. Bull.* No. 37, 1921.

While no published work on pure line selection of rice is more than about a decade old, a large part of the rice of the United States is now produced by strains or varieties resulting from such work, and pure strains are rapidly coming into popular favour in many other lands. Every character of rice of recognized importance—yield, earliness, flavour, cooking quality, size, shape, and colour of kernel, freedom from awns, tightness of grain, erectness of stem, freedom from disease, etc.—has shown itself subject to improvement by this kind of selection. The only limit to the possibility of improvement in this manner is that of the best combination of characters which can be found in any existing individual rice plants. For the combination of points of superiority not to be found in any one plant, recourse must be had to hybridization.

Hybridization is the act of producing a plant with dissimilar parents. There is a definition of hybrid as a cross between two species, but in plant breeding the word is used in the sense just defined. It is accomplished by successful cross-pollination—by fertilizing the egg by the agency of pollen from a dissimilar plant. As rice is usually close-pollinated, and as pollination usually occurs before or as the flower opens, and as the palet and lemma are very tightly united up to the time of their natural opening, it is a very exceptionally difficult subject for effective cross-pollination.

Although many men have attempted to use this method in rice breeding, the single known successful effort (not in crossing rice but in getting a cross of economic value) was made in Java by van der Stok, in crossing *Skrivimankoti* and *Carolina*. As already stated, these varieties are remarkable, the one for high yield but poor quality, the other for very fine quality. The hybrids of these varieties were multiplied as fast as possible, with all necessary use of the space in the selection garden. From the fourth hybrid generation,[1] 314

[1] V. d. Stok, *Verslag. v. d. Leiter d. Selectie- Zaadtuinen voor Rijst*, etc., 1913, p. 16.

cultures were made of the seed of single plants. Of the 91 of these kept for further work, 16 were regarded as "fixed"—that is, as breeding true. The great mass of hybrid material was therefore still composed of plants in which new combinations of characters were appearing with each generation. In each generation, a fraction of the individuals showed the characters in fixed combination, while the remainder were still unstable hybrids, although constantly close-pollinated.

Among the fixed strains the single fixed characters might be those of either parent, or a blend of these, or rarely, by "transgression," an extreme, beyond either parent—as yielding more than *Skrivimankoti*, or eight days earlier than *Carolina*, the earlier parent, or of even finer quality than the latter. One of them was judged the finest rice known, but happened to lack remarkably in vigour. As no reason is known for genetic antagonism between quality and vigour, the possession of hybrid material still freely recombining the parent characters presents the chance that in any generation there will appear a strain in which the best qualities of the respective parents will be in fixed combination.

While this cross is the only one so far productive of material of probable economic value, the possibility of improvement by hybridization is important enough to call for some discussion of methods and principles, and mention of observations made in connection with other crosses, even though these have none of them yet proven of practical value.

The floral structure and behaviour of rice, a knowledge of which is essential for an understanding of the technique of cross-pollination, have been described in Chapter I. As a recapitulation, the flowers open usually in the forenoon, remain open for a period of from many minutes to an hour or so, and then close. Pollination usually takes place just before or at the time of opening. The limited available information does not indicate that the observed differences in time of opening, time of

pollination, etc., are characteristic of varieties, although this may be the explanation of de Haan's statement that the stamens burst about three minutes after the flowers open, while other observers have found it more prompt.[1] With this exception, the observations on the subject agree in finding insignificant differences in averages between varieties, as compared with the differences between individual plants and flowers. Thus Rodrigo, working with strains believed to be pure, and examining fifty flowers of each, found that immediately after the flowers opened the stigmas were free of pollen in 3 flowers of *Binicol*, 4 of *Ininteu*, and 2 of *Binangbang*, some individuals of each having over 60 grains, and the averages being essentially the same—respectively, 18, 21·6, and 20·2.

It is these flowers that open with pollen-free stigmas which present a patent opportunity for cross-pollination, and eventual natural hybridization. Natural hybrids have been reported by a number of writers, but isolated cases lose interest, unless taken advantage of for breeding, when they become numerous enough to be calculated by per cents (de Haan, Hector, Rodrigo, Mendiola). And the extent of natural cross-pollination must be incomparably greater than that of natural hybridization, because the opportunity for pollination by other plants of the same kind is surely incomparably greater than that for pollination by plants of other kinds. Nothing is known in the case of rice as to the respective effectiveness of pollen derived from the same flower as the stigma, and that from other flowers, plants, or varieties. Rodrigo counted the pollen grains falling on an area of two square centimetres, at measured distances

[1] Van der Stok, E. (and Fruwirth, C.), "Reis (*Oryza sativa*, L.)," in Fruwirth's *Züchtung d. landw. Kulturpflanzen*, v. p. 36; V. Breda de Haan, *l.c.*; McKerral, A., "Some Problems of Rice Improvement in Burma," *Agric. Journ. India*, 8. (1913), 317; Hector, G. P., "Notes on Pollination and Cross Fertilization in the Common Rice Plant, *Oryza sativa*, Linn.," *Mem. Dept. Agric. India*, Bot. Series, 6. (1913), 1; Thompstone, E., "Some Observations on Upper Burma Paddy," *Agric. Journ. India*, 10. (1915) 26; Rodrigo, Pedro A., "Pollination and the Flowers of Rice," Thesis, Philippine Coll. of Agric., 1921 (an excellent piece of unpublished work); Mendiola, N. B., *l.c.*

from a flowering panicle, with the following results (averages of 64 counts) :—

Distance .	25 cm.	50 cm.	100 cm.	150 cm.	200 cm.
Number .	21·9	8·1	3·4	1·4	0·06

The stigmas unpollinated when the flower opens cannot be used for artificial hybridization, because they cannot be recognized in the field. It appears further that the artificial opening of flowers before their natural time, removal of the anthers, and closing the flowers again, is not the most successful method, although it might seem *a priori* the most promising. The technique developed by van der Stok and used at Los Baños, consists of cutting off the upper end of the lemma and palet with sharp scissors, a few hours before the flower is due to open, and removing the anthers with fine forceps, doing this to any desired number of flowers in a panicle, removing all other flowers completely, and then bagging the panicle. When the flowering hour arrives the bag is removed, a flowering panicle of the chosen other variety is shaken over the treated panicle so as to dust the stamens with its pollen, and the bag is replaced. A fair proportion of the emasculated flowers produce kernels. These are of the usual length but shrivelled in the unprotected upper part, and so require the protection of the bag. Because they are without their natural protection, they require exceptional care. The practice is to germinate them quite promptly and to do this on sterilized agar containing a nutrient solution.

The fundamental difference in principle between work in hybridization and other breeding work is that, whereas in selection one deals with the individual plant, presenting a definite and fixed group of characters—so fixed in their combination that one usually works on the assumption that they are immutably grouped,—in hybridization the several characters are the units primarily dealt with, and their combination in the single plant is the thing one changes. The identification of the hereditary unit characters is no simple problem, but a

beginning has been made on it. As they are more completely identified, the understanding of the detailed problems of hybridizing any particular plants becomes more accurate, and the practice of hybridization can become more certainly effective.

The most accepted theory of the mechanism of inheritance is that the inherited characters are borne by particles arranged serially along rods or threads called chromosomes, in the dividing or fusing nuclei, and that when fusion occurs the two particles (one from each parent) bearing the same kind of character fuse together, one to one. If the character, for example, be colour of hull and both parents have "white" hulls, the particles bearing the colour-of-hull character will be exactly alike, and the hulls of the progeny will surely be white. In pure lines the fusing chromosomes must bear the same characters, and the strain must breed true. But if one parent have a red hull and the other a white one the daughter plant inherits both characters, but cannot manifest both. *A priori*, its hulls might be of either colour, or a blend of the two, or might possibly be neither, as a result of the inherited tendency to be both; as a matter of observation they will be white, according to Thompstone. If the hybrid daughter plant produced by this crossing be close-pollinated, and hull colour be a real unit character, following what is called Mendel's law of the segregation of characters, then of its progeny about one-fourth will have red hulls and will breed true at least in this respect; about one-fourth will have white hulls and will likewise breed true in this respect, and about one-half will inherit both tendencies and will have white hulls because, as the first hybrid generation has shown, white is "dominant" over red (and red is "recessive") when both tendencies are inherited. This half of the seed will not breed true in this respect; instead, its immediate progeny, like the generation of which it is a part, will show red and white hulls in approximately the proportion of three white to one red. Among the white three-fourths, it is absolutely

impossible to distinguish the one-fourth which will breed true from the one-half which will not. It is therefore hopeless to attempt to rid a field of red hulls, present in a genetic mixture, by means of mass selection.

In the presence of genetic mixtures, the only way to secure a strain which will breed true, except when all of the characters wanted are recessive, is by line selection: planting the seed of each individual plant in a row or group by themselves, and immediately discarding all of the progeny of any plant if any of its individual daughter plants are unlike it.

In the case of glume colour as studied by Thompstone, this seems to be a unit character, strictly following Mendel's law. It is not impossible that all unit characters would be found to follow it, if we could identify them, and analyse into their units the characters we see, so as to understand the action of hereditary tendencies upon one another. Van der Stok (*Verslag*, 1913, p. 16) remarks that phenomena which at first appeared to be irregular, to deviate from the rule, are seen to be perfectly regular when the study of very ample material permits them to be understood.

Reported examples of clear-cut Mendelism, implying hereditary unity of the characters in question, follow. All observers agree that the starchy character of ordinary rice is dominant over "glutinousness."[1] The ordinary size of the outer glumes is dominant over greater length.[2] Extreme shortness of panicle is dominant over the usual length (van der Stok). The clustering of spikelets is dominant over their usual arrangement, one by one.[3] Thompstone's observation that white is

[1] Van der Stok and Fruwirth, *l.c.*; Parnell, F. T., "Note on the Detection of Segregation, etc.," *Journ. of Genetics*, 2. (1921), 209. Parnell reports an excess of starchy grains; and Yasuke, in *Botanical Magazine Tokyo*, 32. (1918), 93, states that the recessiveness is imperfect.

[2] Van der Stok and Fruwirth, *l.c.*, p. 47; Parnell, F. R., Ayyangar, and Ramiah, "The Inheritance of Characters in Rice," i., *Mem. Dept. Agric. India*, Bot. Series, 9. (1917), 75.

[3] Roy, S. C., "Preliminary Classification of the Wild Rices, etc.," *Agric. Journ. India*, 18. (1921), 365.

dominant over red in the hull is confirmed by Hector,[1] more specifically as to "brick-red," and, with qualifications, by a number of writers. Black, in the same structures, is dominant over white (Hector, *l.c.*). White is dominant over golden (Parnell et al., *l.c.*); but four or five factors combine to determine the golden colour.[2] In the awns, red is dominant over white (Hector, 1913), and purple is dominant over red.[3] Brown is dominant over faint yellow, the latter behaving as a unit, but the brown "throwing" red in various calculable proportions (Nagai). In the coats of the kernel red is dominant over white,[4] and black over red-brown (van der Stok). The presence of the pigment, anthocyan, is in general dominant over its absence; thus red is dominant over absence of colour in the stigma (Nagai), and colour is dominant over its absence in the leaf-sheath (Roy).

Without report of dominance, van der Stok states that, as segregation of characters occurs in successive generations of hybrids, the parental sizes of grain reappear unchanged in the fixed hybrids, which suggests that this is a unit character.

Imperfect dominance or a tendency to dominance is shown by earliness over lateness in the crop, and by presence, size, and strength of awns, as compared with their absence or weakness of development (van der Stok); such cases suggest that we have here to deal with complex characters, single units of which exhibit dominance. Transgression in the direction of earliness has already been mentioned. Van der Stok also reports fixed hybrids more bearded than either parent. Among fixed strains of an hybrid of common rice and a Siamese variety with the kernels very slender, and even

[1] Hector, G. P., "Correlation of Colour Characters in Rice," *Mem. Dept. Agric. India*, Bot. Series, 11. (1922), 153.

[2] Parnell, Ayyangar, and Ramiah, "The Inheritance of Characters in Rice," ii., *Mem. Dept. Agric. India*, Bot. Series, 11. (1922), 185.

[3] Nagai, I., "A Genetico-physiological Study on . . . Anthocyan, etc.," *Journ. Coll. Agric. Tokyo*, 8. (1921), 1-92.

[4] Van der Stok and Fruwirth, M'Kerral, Thompstone, Hector, 1913; Hector, 1922; Hector, G. P., "Observations on the Inheritance of Anthocyan Pigment in Paddy Varieties," *Mem. Dept. Agric. India*, Bot. Series, 8. (1916), No. 2.

bent, he reports extremes beyond either parent in both directions.

As a step toward the understanding of the effective inheritance of complicated characters, it is convenient to note the possibilities—assuming that there are in all cases real units, inherited as such without change, whether or not there is interference with their manifestation (as in recessives). (1) The units may be linked in inheritance, in which case we have genetic correlations. Such are presumably a part of the correlations shown by Jacobson and Vibar. If linkage is invariable, so that a group behaves as a unit, attempts to analyse it become purely dialectic ; but in careful work constant linkage will not be assumed hastily. For illustration, we do not know whether the presence of anthocyan is a unit or whether its presences in different structures are such, although it has been studied very carefully by Parnell et al., Nagai, Yamaguchi,[1] and Hector.

(2) The units may be inherited in complete independence of one another. Even then, they may be interdependent in development and manifestation, in which case physiological correlation results. Yamaguchi, studying the hybrids of *Karasumoti*, a glutinous variety with violet-black glumes, and *Shinriki*, a standard rice with the common whitish-yellow glumes, found a marked association between dextrinose endosperm and dark colour of glumes, but believed that the correlation was physiological rather than genetic.

In the present early stage of the development of science in rice hybridization, colour, being easily seen and described, as well as economically important in the case of the kernel, naturally has received a large part of the attention of experimenters, and real progress has been made in analysing cases of complicated inheritance. In Yamaguchi's hybrids all of the first generation had violet-black glumes, but lighter than those of *Karasumoti*. Five distinct colour types appeared in

[1] Yamaguchi, Y., "Studies in Heredity of Colour of Rice," *Bot. Mag. Tokyo*, 35. (1921), 106 ; review in *Internat. Review*, 12. (1921), 1399.

the second generation, and still more in the third and fourth. He concludes that the dark colour appears as the expression of three hereditary factors—a black determinant, a red determinant, and a factor restricting colour to the ends of the glumes. Nagai and Hector have devoted particular attention to the inheritance of colour patterns—the common inheritance of colour by different structures. For the detailed results, reference must be made to their publications.

While, in the act of fertilization, one nucleus from the pollen tube fuses with that of the egg to give rise to the embryo, another nucleus from the pollen tube accomplishes a fusion outside of the egg to give rise to the endosperm. If the parents are unlike, so that the embryo and seedling is hybrid, so also is the endosperm. In a cross resulting from the pollination of glutinous rice by common rice, starchiness being dominant, the result is the development of a non-glutinous endosperm, within the coats derived from and borne by the glutinous parent. This is the phenomenon, more familiar in maize, known as xenia. Parnell has shown that, as was to be expected, the segregation of these characters in hybrids occurs in the formation of the pollen.

True variation, which, if conspicuous or extreme, is sometimes called mutation, is the appearance of any new character otherwise than by the re-combination of hereditary units—that is, by a change in a unit itself, however it may be caused. Acclimatization might be a result of variation under the influence of the environment. The vast number of varieties seems to suggest that rice varies, or has varied, freely. But van der Stok says that true variation in rice is very rare. And, as a matter of fact, no single specific instance of it is known.

CHAPTER V

RICE IN THE UNITED STATES

The field treatment of rice is so exceedingly diverse in adaptation to different economic conditions, different climates, and other environmental factors, and different varieties, and as a mere matter of custom where none of these differences in condition demand differences of treatment, that one comprehensive treatment, stage by stage, explaining its field treatment in general, is quite impossible. The alternative is separate treatment of a number of regions.

Among countries with an important rice industry, the United States is that in which human labour is most highly paid and hardest to hire at any price, and rice must accordingly be raised, if at all, with the least possible use of it. Within the United States the discussion in detail is of California rice, partly because wages are highest there, and California is widely celebrated for the substitution of machinery for hands, but chiefly because intimate personal familiarity is the best guarantee of the competent treatment of the subject in its details.

CALIFORNIA

Rice is only about a decade old as a real California industry. An effort was made to establish it about sixty years ago, and there are old reports of a number of attempts to grow it, successful on a purely experimental scale. The writer, in 1903, planted several

varieties, of which only one reached maturity. The inducement was the presence of a large area of heavy, flat land, very cheap at that time because no profitable use for it was known, but apparently fit for rice. In 1909 the Office of Grain Investigations of the U.S. Bureau of Plant Industry began tests of rice in the Sacramento Valley. These were conducted for three years on private land, and in 1912 the Biggs Rice Field Station was established. The growth of the rice industry in California is shown by the following table:

Year.	Acreage.	Yield, in Sacks of 100 lb.	Average, Sacks per Acre.
1912	1,400	31,500	22·5
1913	6,100	131,850	21·6
1914	15,000	360,000	24·0
1915	34,000	1,020,600	30·0
1916	53,300	1,468,350	27·5
1917	80,000	2,520,000	31·5
1918	106,000	3,155,000	29·7
1919	142,000	3,546,450	25·0
1920	162,000	3,717,900	22·7
1921	135,000	3,280,500	24·3
1922	140,000	3,717,000	26·6
1923	105,000	..	..

California rice is practically confined to the Sacramento Valley. In this valley, it is limited toward the south by the cold winds coming through the gap in the Coast Range, and toward the north by the absence of much suitable land. As a really important crop, it is confined to Butte, Glenn, Colusa, Sutter, Yuba, and Yolo counties. The shrinkage since 1920 is confined to the first three of these, the oldest rice district, and is due to the abandonment of fields because of weediness, along with economic weakness after the loss of crop in 1920. The San Joaquin Valley has suitable land and climate, but not water.

The rainfall in this district averages 20 inches, more or less, practically all falling in the months from October to March. The rice depends entirely upon irrigation for its water. Nearly all of it is obtained from the Sacramento and Feather rivers, and is distributed through ditches maintained by irrigation districts, private and mutual companies, and companies operating as public utilities. The usual cost to the consumer is from a dollar to a dollar and a quarter an acre foot, but in some places it is cheaper than this. There is very limited irrigation from wells.

Aside from the absence of rain during the growing season, the chief climatic features of the valley are cloudlessness, hot days, and cold nights. Day temperatures above 100° F. and night temperatures below 60° F. are common in June, July, and August. The clear sky and hot days favour the growth of rice, and the cold nights check and delay it. Different varieties do not respond alike to the combination. In general, tropical varieties have their development so checked by the cold nights that they fail to mature, and semi-tropical varieties, like the Honduras rices of the Gulf states, cannot be grown with any confidence that the fruit will ripen. Varieties from colder lands, on the other hand, suffer so little from the cold nights that the latter are offset by the hot days. The result is that, of the many varieties which have been tried, practically none except Japanese are now grown; and there is no present prospect of growing any others, unless it be of the Piedmont type, of equally Northern immediate origin.

All California rice land is rather heavy, and a large part of it is a very heavy adobe clay. It is also considered necessary that it have an impervious subsoil or hard-pan at no great depth. If one foot deep it is rather too near the surface; if it is six feet down to it, the land is likely to require too much water. It is agreed that almost any land, properly irrigated, will raise rice, and the demand for heavy land with a hard-pan is because

such soils hold water well. It is also believed, and may probably be considered proved, that the heavier soils continue to produce, after a number of years, better than light ones. One of the chief reasons for the rapid development of the rice industry here was its use of lands not highly valued for any other crops. In part, these were lands which had once produced fine yields of wheat but had been worn out by steady use for the one crop, and fallen to a fraction of their old cash value. And in part they were lands which, mostly because of alkalinity, but in some instances for other reasons, had never been of much use until they were found good for rice. The good old wheat land seems best to maintain its capacity to produce good rice crops.

Irrigation was no sooner practised on a large scale than drainage was found necessary. In minor part only, this was for the sake of maintaining the rice land in good condition. It was more immediately required in order to prevent damage to neighbouring lands in other use by the raising of the water table in the soil. In Glenn County there has been an attempt to obviate this by legal delimitation of the area where rice may be grown. But the chief demand for drainage systems has been to prevent damage by the flooding of lower-lying lands, by the water seeping or leaking from the rice or deliberately released from it. Such damage, threatened damage, and alleged damage have been a fertile source of lawsuits. Litigation over water rights and drainage has made rice in some seasons a better business for lawyers than for anybody else.

Drainage questions have been largely solved, but the danger of litigation over water will not end until there is a comprehensive adjudication of all water rights in the watershed.

There are material differences in the handling of rice on new land and on land which has raised one or more crops of it. Smooth old grain or pasture land may as well not be ploughed for the first crop—although the Government bulletins recommend ploughing it the pre-

ceding autumn. Such lands have frequently produced fifty sacks to the acre, and there are much higher records. Ploughing may perhaps increase the yield. But such lands produce luxuriant rice vegetation always, and produce later crops than old land. Ploughing makes them later still and slower to dry and harden for harvest, and the rice more likely to lodge. It cannot be emphasized too strongly that the one natural peril of California rice is the fall and winter rain. A week's delay in harvest may result in complete loss of the crop, and ploughing new land delays the harvest by more than this. In my own opinion, not only ploughing, but any cultivation at all of new land is wasted, unless it is necessary in order to smooth or even it. Parts of the same field, well disked, poorly disked, and untouched, have been indistinguishable after the water was impounded, while a very thoroughly cultivated adjoining field produced apparently about the same yield of grain, but later. If there is on the land vegetation that can endure submergence, it is necessary to plough to get rid of it, but this is unusual.

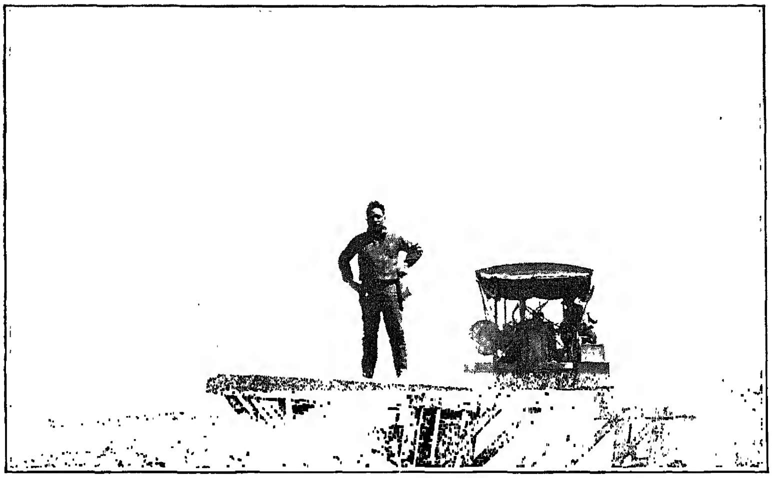
Assuming that the land is not cultivated, it is prepared for rice by providing the necessary ditches to serve it with water, "checking" it with dikes, and placing the gates. The service ditch must have ample capacity for the first irrigation, must of course cover the highest parts of the field, and be too well constructed to leave any chance that its walls or gates will break out during their first use. They are never lined, but the loss of water from them is not considered serious. Cross-gates are placed wherever necessary to raise the water over any part of the field. It is safer to install wooden ones, which will last several years, than to build concrete ones on new land; most engineers are inferior to experience in determining their best final location. It is not California practice to extend the service ditches to all parts of the field, but rather to let the water run from check to check, even for half a mile or more. The only time that this offers any difficulty is in the first

irrigation, when a great deal of water is absorbed by the soil and the checks next the ditch have to be kept wet until the last checks are well watered.

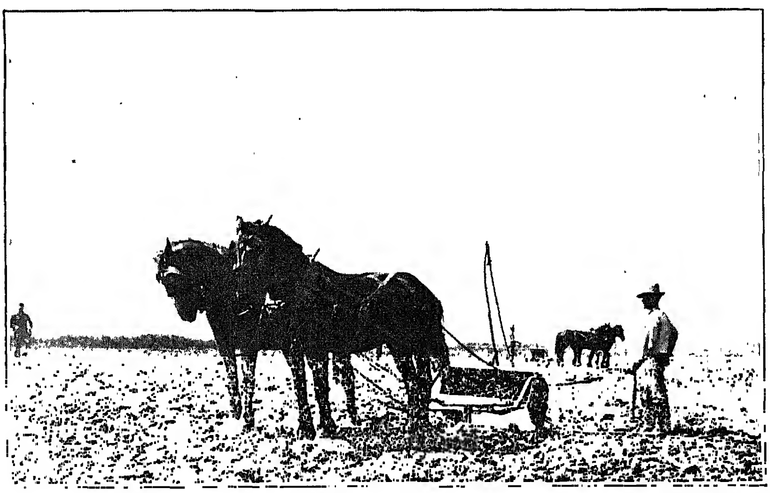
The location of the dikes or levees is the work of a surveyor or engineer, who works most efficiently with two helpers. The contour interval is usually three inches or three-tenths of a foot, except where broken ground makes a greater interval necessary in spots. The surveyor sets up his level at the upper end of the field and locates his rod-men on the two nearest desired contours. The rod-men are then signalled along their contours, each planting a succession of stakes. Close behind each of them follows a single plough, marking the line by the furrow. The ploughman may well ignore minor irregularities in the contour, so that the furrows will be reasonably straight, as nearly parallel as may be, and especially without sharp curves. After the field is laid off and marked by the furrows, a tractor, pulling 8 feet or more of ploughs, runs along each side of each furrow at a distance of a foot or more, throwing the dirt toward it; this loosens the ground for the "checker." The latter is a huge V, open about 30 inches at the narrow end and 18 feet at the wide end, 2 feet high at the wide end and 42 inches at the narrow, made of three-inch planks, well braced, shod and bound with iron. It is drawn, wide end first, by a tractor of at least 60 h.p., and leaves the finished dike in its trail. It is the most startlingly efficient implement in the California rice fields. It costs about $150.00, made locally. A higher-priced one, of iron throughout, better equipped to turn at the ends of the dikes, can be bought.

The Government bulletins[1] have steadily advised a different type of dike, at least 10 feet wide on the base, with gently sloping sides over which machinery can

[1] Chambliss, C. E., "A Preliminary Report on Rice-growing in the Sacramento Valley," U.S.D.A., Bureau of Plant Industry, *Circular* No. 97, 1912; Chambliss, C. E., and Adams, E. L., "The Culture of Rice in California," *Farmers' Bulletin*, No. 688, 1915; Chambliss, C. E., "Rice-growing in California," *Farmers' Bulletin*, No. 1141, 1920.



THE CHECKER.



THE FRESNO SCRAPER.

To face page 170.

work freely. On new land cost is the only objection to such dikes, and they would facilitate the harvest very materially. But they would be hard to get rid of or move, and experience of a season usually shows some changes in the contouring to be wanted. On old weedy land such dikes would be intolerable.

After the checker has done its work, the dikes have still to be finished at the ends; this is done with scrapers called Fresnoes, drawn by two or four horses. There are also likely to be places along the dikes which require touching up; it is better to do this with the Fresno in advance than to have to do it by hand after the water is on the field.

Some growers postpone planting the gates until after the first irrigation, and may be guided in placing them by observation of the field with the water on it. But if the better type of gates are used, it is better to place them in advance, unless this involves any delay in the first irrigation. Two types of gates are in use. The simpler consists of merely enough boards on the ends and bottom to hold the gate in place and provide a guide for the flash-boards. The better type, or box-gate, is a box, open on top except for a tie-board, open on the lower side, and closed as may be desired by the flash-boards on the upper side. A sill, 6 inches deep, keeps water from eating under it, and the ends are similarly carried out and embedded. Forty-two inches wide and 14 inches deep is a convenient size of opening. For control of the water each gate is provided with one 6-inch, one 4-inch, one 2-inch, and two 1-inch flash-boards. The bottom of the opening of the gate should be in the plane of the ground surface, never any higher. The gate should be placed where it will drain the check thoroughly; very large checks require several gates in each dyke. Except as the lie of the land may make it inexpedient, the most convenient place for the gates is uniformly about 30 or 40 feet in from the side of the field. Care in planting the gates is essential. Lowering them afterward is much more arduous than planting

them the first time. And if they are insecurely placed and wash out, there is no near limit to the mischief likely to result.

For reasons already explained, an early variety of rice is especially desirable on new land. The standard rice of the valley is *wataribune*, originating from distribution by the Government experiment station and from two direct importations of seed from Japan. Late *wataribune*, the station variety, is a quite pure strain, too late for use on new land. Early *wataribune* is a mixture, with not less than fifteen distinguishable and mostly quite diverse minor strains besides the typical predominant one. The latter is about ten days earlier than late *wataribune*. It is the most widely planted rice in the valley on all lands, new and old.

"1600," a pure strain developed by the Government from the Italian *Chinese* and recently named *Colusa*, has been grown widely as a first crop. It produced almost as heavy a crop on such land as early *wataribune*, and is fully a week earlier. If properly harvested, it is an equally good milling rice. But it is more subject to sun-cracking, perhaps only because it is earlier, and shatters decidedly worse, so that considerable loss results if it is not harvested promptly when ready. On old land it yields too poorly to be worth growing. *Onzen* and *Suehiro* are other Japanese importations, a week or more earlier than *Colusa*. *Suehiro* had some vogue several years ago, but has gone out of use, partly because it did not yield uniformly well, and partly because, in contrast to the countless varieties which cannot be produced in California because they shatter too freely to stand binding, its grain is too tight to thresh out well. *Onzen* is a very early and good milling rice of the *wataribune* type, in increasing use. In general experience, the crops are light, averaging below 30 sacks where well handled; but there is an authentic record of 53 sacks on one old field. These Japanese varietal names have no necessary connection with the names of varieties in Japan. *Onzen* is there merely a place-name, and

wataribune means "went over in a boat,"—that is, imported or exported.

The writer's *French* rice, secured from France under the varietal name *Française*, is of the Piedmont type, with larger and flatter grain than the California Japanese rices. It is rather earlier than *Onzen*, and in the limited experience to date is the most productive of the very early varieties. It is especially suited to new land because it thrives with less water than any other rice grown here, and on new land water does not have to be held deep for weed control. Expert Japanese rice men declare that it is an upland Japanese variety, and must originally have been sent to Europe from Japan. Like many potential upland varieties, it endures deep submergence well. The explanation of its power to produce heavily and early is found immediately in its ability to thrive at low temperatures. A month after planting, in the relatively cool spring weather, it overtops any other local rice by half.

Seed, of whatever kind, should be clean and sound. The broken rice and weed seed removed will usually more than pay for the work of cleaning. And on new land it is particularly worth while to avoid planting weed seed with the rice. It pays to test the germination of the seed, but very few farmers do this; if the per cent of germination is below 90, there should be a corresponding increase in the amount planted. On uncultivated land the drill will not bury the seed, and is not worth using; it will not justify using enough less seed to pay the extra cost, seems not to increase the crop measurably, and requires time. The native vegetation will keep the seed from washing away, except in the borrow-pits, where the loose soil has been scraped away by the checker, and where the first water runs because the grade has been lowered. An improved stand here can be secured by harrowing or disking after the dikes are erected. General practice is to broadcast 90 or 95 pounds of *wataribune* to the acre, and at least a sack of any other variety; on land believed to be poor, the

seeding is heavier. This looks like a needless and excessive amount of seed. It is ten times the amount apparently necessary if all seed could grow and be equally spaced, and *wataribune* is a very free-stooling rice. Still, growers are generally agreed that it is unsafe to use less than this amount.

The first irrigation is in order as soon as the seed is in the ground, and the season properly dates from the first irrigation. Spring is usually so cold or wet that it is impracticable to make this date earlier than April 15. At the Biggs station it has been found that of plantings at fifteen-day intervals, from April 1 to May 15, the earliest invariably produced the best yield, each subsequent sowing producing four or five sacks less than the preceding. In time of harvest the gain by early planting is less considerable, unless the start is delayed into hot weather. The earlier the start the less advisable it is that the seed be drilled into the ground, because of the danger of its rotting. The first irrigation must be thorough and should be brief. To avoid prolonged submergence of the upper checks while water is passing through them to the lower ones, it is very essential that there be an ample head of water for its first application. At this point the man irrigating from wells or from a small ditch is at a serious disadvantage. For one thing, he must provide service ditches reaching the finer divisions of the field. But he is limited still as to the size of the single checks. For economy of harvest, the larger they are the better. On very even ground they even reach a size of 50 acres; but a head of 4 second feet, sufficient at other times for more than 200 acres of small checks, may never be able to cover this area of dry ground in one check. Irrigating a field of somewhat more than one section (640 acres), I have been glad to use a head of 50 second feet for the first irrigation; such a head is rather a luxury, but will give an idea of the advantage of ample ditches and gates at this time. As most growers usually are ready at about the same time, and the demand for water is, for a brief

period, above the capacity of any canal or pump system, there is an added advantage in being ready to begin before the rush. The land is likely to be so dry by May 1 that 6 acre inches per acre will be needed to irrigate it, leaving the least possible surplus to be drained off. Because the ditches and dikes are previously untested and may break in places and have to be repaired, and because of the need of haste, the first irrigation is a strenuous operation.

As soon as all the land is well wet it is best to drain off all remaining water. To keep the field uniform the dikes should be cut to drain all pools or ponds which are not drained by the gates. The land is then allowed to dry for a number of days. It is then flushed again in the same manner, but much more easily, because much less water is required and the dikes are quite sure to hold. Germination should become evident and general immediately after the second irrigation. After another period of drying, the land is flushed a third time; and there may be a fourth and fifth flushing before the water is finally impounded. After the third or fourth flushing it is good practice to let the ground become dry enough to begin to crack. It does no harm if, at this time, the seedlings wilt during hot afternoons; water may be withheld even until they begin to turn yellow. Such treatment promotes free and uniform stooling and produces sturdy plants. After this strengthening of the plants by drying, the water is held on the rice, shallowly at first, and then gradually deeper, reaching a maximum depth in or before August. From the time the water begins to be held, the California practice is never to lower the water until the rice is nearly ripe.[1]

For several years it was the practice to attempt to remove the weeds by hand, beginning as soon as they could be detected and pulling all that could be found,

[1] For a very thorough description of rice irrigation in California and of experiments on the subject, see *Univ. of Calif. Exp. Station Bulletins*, No. 279, 1917, by Ralph D. Robertson, and No. 325, 1920, by Frank Adams. For these, apply to the University of California, Berkeley, California.

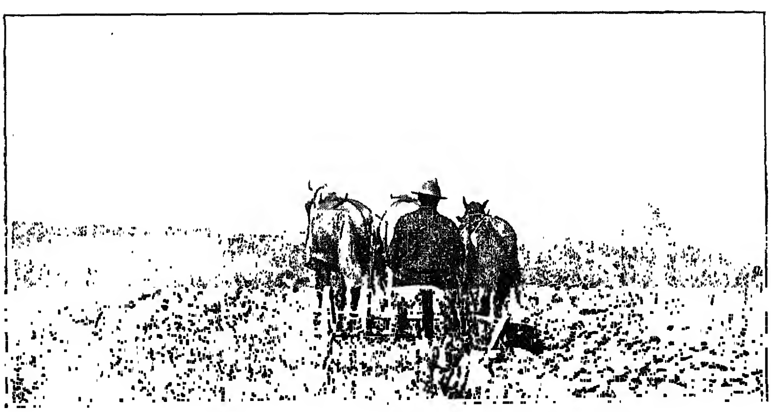
up to the time that the rice was nearly enough ripe to be injured by walking through it. On new land only, this probably pays well. One day's work to the acre will remove the evident weeds from new land, and leave the field appreciably cleaner for the second crop. It was formerly considered worth while to keep the field as clean as possible by hand-work for one or two years more, and large sums have been spent in such efforts, especially during the years of high prices. But with ordinary rice prices much such work is impracticable, and other methods of weed control have been developed.

After the first crop the best field practice is essentially different from the start. Unless it involves very considerable delay the cultivation of land which has already raised a crop of rice can hardly be too thorough to be profitable. The dikes may be ploughed down and the field ploughed and cultivated as a whole, or the work may be done check by check inside the dikes. The added cost of working in small units approximately offsets the cost of tearing the dikes down and replacing them. Almost all rice land is ploughed with large tractors, usually of at least 60 h.p. Ploughing inside the dikes, such machines cannot do a finished job, and must be followed up by small tractors or horse-drawn ploughs. The chief argument in favour of working inside the dikes is that, year by year, the checks become more level; soil from high spots works into the low ones and the borrow-pits along the dikes disappear. On the other hand, old dikes require more hand-work to maintain a maximum depth of water.

Very few fields are uniform in slope; most are broken by sloughs and low knolls. The former, if deep, are accepted as existing conditions and utilized as drains. But sloughs shallow enough to be planted are always uneven in detail and yield unevenly, but cost more for cultivation per acre than the better parts of the field. If they are ploughed and scraped until level, the increase in crop within two years pays for the work and leaves a much better field. The knolls, if not too

GANG-PLOUGH AND TRACTOR.

Photo by Silayan.



PLOUGH FOR SPOTS MISSED BY GANG-PLOUGH.

Photo by Silayan.

To face page 176.

high to be irrigated, produce an inferior crop the first year, and later become altogether unproductive because of weeds, and are centres of weed infection. It pays to cut them down, although their sites may be expected to yield poorly immediately after such treatment.

It is only in exceptional seasons that ploughing would be possible after the harvest. *A priori*, the long time between ploughing and final cultivation,—say from November to March or April,—if ploughing is done before winter, might be expected to improve the soil by aeration; but it is doubtful if the actual aeration so accomplished is better than that during the short period after spring ploughing. Spring ploughing is much more effective in killing weeds, perennial as well as seedlings of annuals. Its disadvantage is in the delay in planting and irrigating. It is already late in March almost every year, and late in April in exceptional years, before ploughing is practicable. Either to gain time or to save expense the usual practice is to plough, double-disk, and plant. A second disking or harrowing, and finally a thorough dragging with a heavy float, are very well worth while.

If the time permits, the incidental cultivation may be a sufficient reason for drilling the seed; but this is inexpedient if the first water is to be held, and in all cases the drilling should be as shallow as possible. There is no chance that seed will germinate in freshly cultivated heavy adobe without irrigation; and if it is drilled two inches deep, as has been recommended, the seedlings will be delayed seriously in reaching the stage where water can be held on them. Ten lb. more of seed is used the second year than the first, and an additional 5 lb. or more on still older land. In the earlier experiments on this subject at the Biggs station[1] the rates of seeding were 100 lb. or less. From 1918 on they were 110 to 150 lb. The results from year to year are very conflicting, but on the whole indicate profit

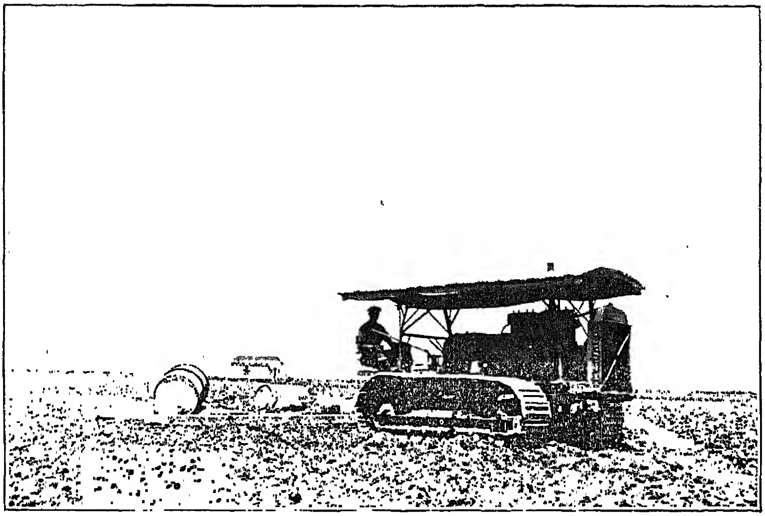
[1] Jones, J. W., "Rice Experiments . . . in California," U.S.D.A., *Dept. Bull.* No. 1155, 1923.

from heavier seeding than has been usual. Poorly prepared land requires much seed; and the control of weeds by water makes heavier seeding advisable.

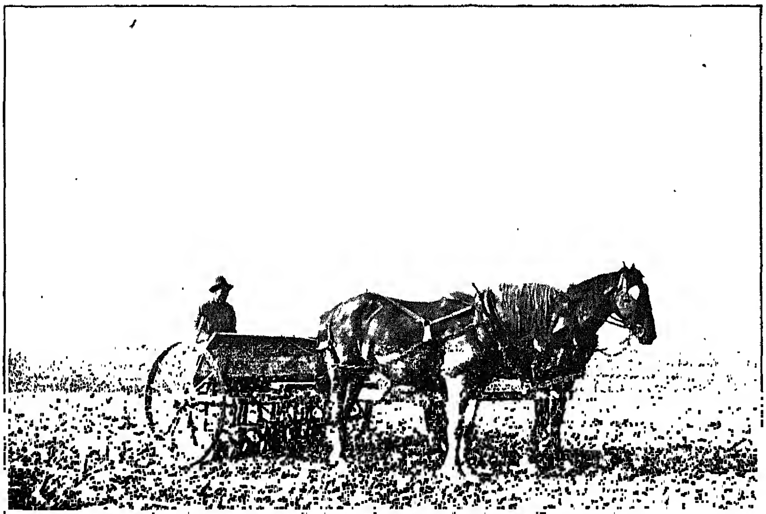
The favourite varieties on old land are *wataribune* and *caloro.* In the order of decreasing productivity they are late *wataribune, caloro,* and early *wataribune.* The first two are pure strains if care is taken to get pure seed, and therefore ripen all at once. The disadvantage of the late *wataribune* is its lateness, and the consequent risk of loss or damage. It is not only the heaviest yielder, but is also the most certainly fine rice if well ripened. Perhaps because of its lateness it does not sun-crack badly. And it is a very hard rice, milling well, and less subject than most varieties to damage by moderate moisture in the sack.

Caloro is a strain developed from *wataribune* by the Biggs station, rather earlier in effect than early *wataribune* because it ripens evenly, and a rather better yielder. Its disadvantage is that it is a softer rice, more prone to hold water and to be damaged by it; wherefore, if not thoroughly dry, it is unpopular with the mills.

The control of weeds is the outstanding consideration in the particular treatment of old land. It has been a general idea in the valley that the use of land for rice for more than three successive years is unprofitable, and that after the first three years it should be rested at least one year out of three, that is, planted not more than two years in succession. As to changes in the land itself, it is certainly true that it loses promptly the peculiar though ill-understood properties of virgin land as regards rice and becomes incapable of producing the huge crops of the first year. Crops have been regarded as very satisfactory if they amounted to 45 or 50 sacks the first year, 35 or 40 the second, 25 or 30 the third, and anything over 20 thereafter, and 30 or more after resting. But there is no evidence at all that changes in good adobe land, by depletion or otherwise, are responsible for decreases after the drop to the second



DRAG, OR FLOAT.
Photo by Silayan.



SEED-DRILL.
Photo by Silayan.

To face page 178.

crop, or at most a slight decrease to the third. With time, depletion must, of course, become a factor. On some soils its incidence may be prompt. But on the strong adobe there is ample ground in experience for the belief that it has not begun to be felt.

Continually decreasing yields, and the necessity of giving rice up for a time, are due rather to the prevalence of weeds alone. No amount of hand-weeding can avoid this, nor postpone it very considerably. After the first year, hand-weeding of most weeds for the conservation of the land is futile. Attempts to prevent infestation by the commonest weeds are likewise unavailing, although clean seed should be used and the sources of water be kept clean. The seed are borne by the wind, by birds, and by winter water, none of which can be controlled, as well as by other animals, irrigation water, machinery, and seed, which can be kept more or less clean. A number of weeds have become so prevalent in the valley that it is vain to hope to exclude them from any field. Their presence must be anticipated. And rice must be given up while they thin out locally for want of water, or else they must be attacked by cultural methods, not as individuals. Practical cultural methods have been worked out for the control of the weeds responsible in the past for the loss of crops and the abandonment of land.

Kennedy [1] lists the following California rice weeds :

Water grasses, *Echinochloa Crus-Galli* :
(*a*) Early form, mature before rice heads.
(*b*) Midsummer form, mature before harvest.
(*c*) Late form, in full seed with the harvest.
Cat-tail, *Typha latifolia.*
Red rice, *Oryza rufipogon.*
Red-stem, *Ammannia coccinea.*
Joint grass, *Paspalum distichum.*

[1] Kennedy (Prof.), P. B., "Rice Weeds," in Smiley's *Weeds of California. Calif. State Dept. Agric. Monthly Bull.* 11. (1922), 227. Kennedy, P. B., "Observations on some Rice Weeds in California," *Calif. Agric. Exp. Station Bull.* No. 356, 1923. This bulletin, received after this book is written, contains a much longer list of weeds and is copiously illustrated.

Canary grass, *Phalaris paradoxa* and *P. brachystachys*.
Scale grass, *Leptochloa fascicularis*.
Umbrella plants, *Cyperus diandrus* var. *castaneus*, *C. virens*, and *C. erythrorhizos*.
Spike rush, *Eleocharis palustris*.

Of these, if there is any species properly called *Oryza rufipogon*, it has at any rate no present status as a California weed. There is a trace of red rice in many fields, but no such rice has shown here any tendency to shatter and increase as a volunteer weed. Joint grass is occasionally found on dikes, but more often on new than old land; it is not a competitor of rice. Canary grass, with timothy, wild oats, broom, rye grass, and many other grasses, grows on what becomes rice land; all of these survive near rice, and none of them amount to anything as rice weeds. Of the "umbrella plants," *Cyperus diandrus*, *C. erythrorhizos*, and *C. virens* grow in the edge of the water, and occasionally out in the checks; they once looked dangerous, but have proved not to be so. *C. erythrorhizos* makes dense clumps on the sides of the dikes, but is easily held in check by ploughing. *C. difformis* is a Japanese species of recent introduction, almost certainly imported with seed, and very likely with seed of *Suehiro*. It spreads rapidly, is not well controlled by cultivation, and its control by water remains somewhat doubtful; submersion will not drown it. In checks where it was present three years ago it has not grown worse; but it cuts the yield down, and needs to be studied. *Ammannia* is a weed easily recognized by the fact that its stems burst near the base when submerged. It is sometimes abundant enough to reduce the crop, but is never responsible for the abandonment of rice cultivation.

A number of other weeds should appear in such a list. Willow and cottonwood seedlings always appear in rice. They cannot grow up through water and are killed by ploughing. But along ditches and on dikes, if the latter are permanent, they will become trees unless pulled or cut. Smart-weed, *Polygonum lapathifolium*,

sometimes grows on the edge of the checks, and out into them much farther and more persistently than do joint grass and crab grass (pictured as a weed by Dunshee), but is still no serious pest. The water plantain, *Alisma Plantago*, sometimes reduces the yield in deep water where the stand of rice is poor anyway. A willow herb, probably *Epilobium californicum*, grows on the dikes and near the edges of the checks and may reduce the yield slightly. A small-flowered aster, *A. exilis*, with altogether the aspect of a large willow herb, is sparingly present in most fields and makes itself a nuisance on old ground not ploughed. On such land it reduces the yield appreciably and may be thick enough to obstruct binding and threshing. It is sometimes called indigo plant, probably because there is a rice weed so called in the Gulf states. Ploughing in the spring gets rid of it thoroughly for the season. Two rushes, a variety of *Juncus effusus*, the bog rush, and *J. xiphioides*, the marsh rush, are occasional weeds, chiefly at the edges of the checks; they yield to ploughing in the spring. The common dock, *Rumex crispus*, is sometimes a nuisance, but gradually disappears from land steadily in rice.

One other weed of the land may be mischievous, although it does not compete with nor injure the rice plant. This is the darnel, *Lolium temulentum*, known locally as cheat. It grows and ripens its fruit and dies in the spring while the rice is starting. But, unlike most grass vegetation, its stem stays erect through the summer's water. It is cut with the rice and threshed with it, and as no easy mill treatment will separate the cheat from the rice its presence lowers the value of the rice very materially. Spring ploughing eliminates it.

While many other marsh and aquatic plants are occasionally found in rice, the foregoing list embraces all that can properly be called weeds in California, except "wire grass," cat-tail, and the barn-yard grass with its numerous forms or relatives. These are the really bad weeds.

The spike rush, usually called wire grass by rice growers, forms mats, which enlarge and become dense if let alone. It yields to thorough cultivation and drying out, and to no other treatment; and the mats become so dense and hard that poor ploughing does not eradicate them. No rice grows in these mats and, as they spread during the season, the rice they reach is made practically valueless. If the corners of the checks are skipped in ploughing they become mats of wire grass; but if they are well ploughed and worked up in the spring the wire grass is disposed of for the season.

The cat-tail is always ready to take quick possession of the entire field. It sometimes pays to cut or pull the larger ones by hand for the sake of the current crop, but it is vain to try to conserve the land in this way. The only way to destroy it is by ploughing and letting the ploughed land dry thoroughly; this kills it, quickly and quite completely. Fall ploughing does the job imperfectly because the land is unlikely to dry well enough before the winter rains come and slack and settle the clods, so that the underground stems of the cat-tail are protected while they get a new start. Spring ploughing may precede planting by only a week or so; but this is usually dry weather, and the drying out while the cultivation is finished usually kills very nearly all of the old cat-tails. Low spots may be less thoroughly ploughed, unless care is taken for this purpose, and may dry less perfectly; wherefore old cat-tails sometimes infest the low spots on fields otherwise free. Countless seedlings of cat-tail appear in the fields every year, and sometimes become large enough to do some damage their first year. It is possible that they could be rendered harmless for the season by drying the field out after the barn-yard grass has been drowned and the rice has become strong enough to endure such treatment. Ploughing in the spring not only kills cat-tails, rushes, wire grass, and other perennials better than fall ploughing, but also catches the seedlings of other weeds soon after they germinate and destroys them; while

the most that fall ploughing can do to them is to bury the seeds, and do this imperfectly.

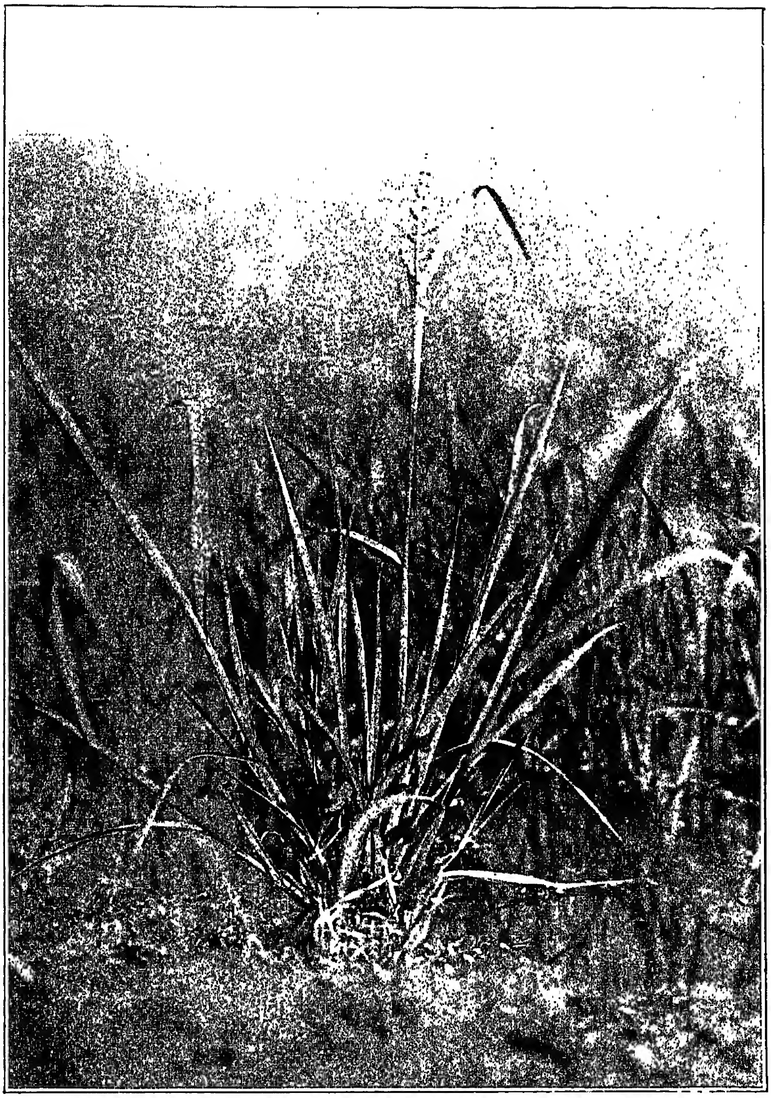
The distinguishable forms of the water grass, *Echinochloa Crus-Galli* and its varieties or relatives, number more than half-a-dozen, but they can be reduced to three for agronomic purposes. One comprises all forms normally maturing and shedding their seed before the harvest. Besides the commonest form, this group includes large slender forms, quite red or almost clear green or yellow, awned and awnless, and strict or branching. The commonest form is usually rather small, very sparingly awned or hairy, and very early; where moisture conditions are favourable, it can pass through several generations in a season. It has been common here since long before the introduction of rice. The other two groups ripen late enough to hold their seed and be threshed with the rice. The one called Japanese millet is apparently a recent introduction, probably with rice seed. It is copiously awned with a rather strict panicle. The whole plant turns a yellowish-brown before it is mature. It forms dense and very firmly rooted clumps on wet ground, but stools sparingly in water. When young it looks so much like a coarse rice that the absence of a ligule must sometimes be used to distinguish it. The third type forms looser tufts when it can form any and is easily pulled up. It is very tall, with wide green leaves, and the fruit is green until fully ripe. I have never seen it except in the rice, and suspect it too of having been brought in with the rice. All of these forms have value as forage. The dried hay from a small measured area of mixed summer forms, where some water stood after they were too tall to be hurt by it, weighed at the rate of 4½ tons to the acre.

It has proved impossible to guard the fields effectively against the entrance of all or any of these forms of water grass. And they produce seed in such numbers and of such vitality that, however the land may be cultivated, enough remain on or near the surface to infest the field.

Resting the land for a year, with or without ploughing, does not reduce the number enough to permit even one really good crop. Even land rested and fallowed one season, and used one year for dry grain, is badly infested with water grass when returned to rice the third year. Experiments at the Biggs station several years ago led to the conclusion that temporary practical freedom from these weeds could be secured by repeatedly irrigating to start the water grass and then ploughing to kill it. But such treatment is expensive, while the land makes no return and may then make only one good crop possible. An irrigated and clean-cultivated crop might accomplish the purpose, but I have never seen one tried successfully.

The effective mastery of the barn-yard grass has been accomplished, however, by an entirely different method—drowning it. That this was possible has been more or less generally understood for several years, but the successful attempts have been mixed with failures to drown the grass and with destruction of rice by drowning it, and by its becoming dry while it was too tender to survive drying.

What positively can be done is illustrated on a field scale by the writer's 1922 crop. The first irrigation took place from the 11th to the 18th of May. The field was then allowed to dry except for some spots and sloughs. The second water was held, deeply enough to cover all of all checks, except for a few high spots and one area where the contouring was wrong. On these spots and area the yield was from nothing to fifteen sacks (estimated), the rice being suppressed by water grass. On the remainder of the field the water grass varied from absent to present in too small amount to do appreciable harm. The yield on different measured areas, including the sterile spots and area, ranged from 29·5 to 43 sacks. The lowest (29·5) was from four large checks, 61 acres, one of which could not be irrigated properly; the yield on the other three must have been about 35 sacks. The significant thing is not so much a



BARN-YARD GRASS.

To face page 184.

35-sack crop on land planted the fifth successive year, as the fact that this was heavier than that of the fourth year by 9 sacks, certainly due largely to the drowning of the water grass.

In using water to suppress water grass there are clearly two problems—drowning the water grass, and not drowning the rice. The growth of rice under water at various temperatures has been discussed in Chapter I. My own field experience is that it can germinate and grow through more than 8 inches, applied at any time after May 15. Silayan's experiments indicate that at the lower temperatures of early spring it can do the same, but very slowly. Where the depth is considerable from the first irrigation on, the stand is more or less hurt, and the ripening may be less uniform because the thin stand results in persistent stooling. On new land, uncultivated, drowning seems to be easier, due perhaps to the standing and decaying vegetation. The stand is far more likely to be destroyed or injured where the seed is drilled than where it is broadcasted.

On the drowning of water grass and other weeds, I have, besides field observations, the unpublished results of laboratory study by H. F. Copeland at the University of Wisconsin and Mr. Silayan at Stanford University. The basic field observation is that on *hot* sunny days submerged seedlings are killed; it makes no difference whether they are 1 or 4 inches tall, deeply or shallowly submerged. During cool or merely warm weather they may live submerged in vast numbers; and, when the hot day comes, die promptly, decay, float, and make the air foul by the mass of rotting vegetation, while the field is left to the rice alone. Exact determination of the water temperature required is wanting, but it is decidedly high. Such days may not come before June and the water must be there and ready when they do come, and at this time the water grass must be completely submerged. As one cannot anticipate the hot spell and submerge deeply just before it, and it might come too late to be effective if the water grass were permitted to

grow freely, the water is held steadily after germination. This checks the growth of rice somewhat, makes it stool less freely at first, and makes it soft and weak. It checks the growth of the water grass still more considerably.

At low temperatures up to somewhat above 10° C. (50° F.) the common barn-yard grass germinates and grows better than the other forms, as fast as *wataribune*, *Colusa*, and *caloro*, but not as fast as *French*. At and above 24° the Japanese millet grows faster than any other water grass tested, faster than these Japanese rices, or *Honduras*, or the Philippine variety *Iray*, and about as fast as *French*. The typical barn-yard grass is least able to grow under water and first to succumb to hot water. In the Wisconsin experiments it never grew through water more than 3 cm. deep, and in only one instance grew through 1 cm. of water at a temperature of 28° or higher. At and below 20° it germinated and grew through 1 cm. of water ahead of the tropical rice varieties. The Japanese millet, submerged, grows faster than *Honduras* and *Iray* at temperatures from 16° to 28° and under not more than 5 cm. of water; under 10 cm. it usually reached the surface behind the rice if at all. It is evidently harder to drown than the barn-yard grass, but can be drowned in warm water while the rice survives. There are no laboratory data on the late, large, green form, but field observation indicates that it drowns under the same conditions as barn-yard grass.

Field experience has not positively covered the relation between time of first irrigation and the control of water grass with water; and the laboratory experiments, chiefly because rices of tropical origin were used in the Wisconsin work which was the more thorough with the weeds, do not furnish a clear guide. The Stanford experiments show that the rices of northern types can continue to grow for more than a month under water at temperatures down to 9° C.; but at the same low temperatures barn-yard grass germinated and remained alive, growing slowly.

Experiments by Dunshee,[1] made in 1922 on plots of an acre, more or less, began May 1, and show the effect of submergence immediately after broadcasting to be better than that of later submergence of a drilled field or immediate submergence of a drilled field.

In the fields submerged eight inches no barn-yard grass appeared above the surface of the water. There was a scattering of barn-yard grass in the plots submerged six inches, while a considerable quantity of grass came through four inches of water.

In an experiment on date of starting, cultures were started at half-monthly intervals from April 15 to June 1; the earliest gave much the best crop ; all were submerged from the start.

It should be very clearly understood that this procedure for the drowning of water grass is distinctly a California method and may be impracticable or have to be differently managed elsewhere. Practices developed in Italy and India are the same in principle but different in important details.

It should also be emphasized that it is not safe to undertake to drown water grass without the most complete assurance that ample water will be available. This is not merely because the water grass must be submerged completely or it will not drown. Submergence weakens the young rice for a considerable time during which a measure of dryness, probably good for rice which has not been kept under water, is fatal to rice which has been so treated. Eventually this weakness is outgrown. At the end of July, for the purpose of weakening cat-tail seedlings, I have dried out checks on which the water grass had been drowned until the ground cracked without injuring the rice. Incidentally, the cat-tails were not much injured. The attempt might be successful a little earlier. The varieties *wataribune* and *caloro* are no more disposed to lodge,

[1] Dunshee, C. F., "Results of Rice Experiments in 1922," *Calif. Exp. Stat. Bull.* No. 354, Berkeley, 1923. The 1923 experiments were better planned and are much more conclusive, but have not yet been published.

floods released are beyond the capacity of any drainage system and expose the rice industry to merited restraint by injunction against any drainage. To protect the industry against this, some canal organizations have exacted agreements that growers would release no water until ten days after they ceased to take it. In the absence of rain this leaves but little water to be drained off. And in any field the grower can, during this period, dry his upper checks, where the rice is likely to be mature first because they were the first irrigated in the spring, and hold the water in his lowest checks. I have had all the water that would drain from a field of 360 acres, with 7·2 feet total difference in elevation, concentrated on the lowest 10 acres before any was allowed to drain to the outside. No release at all of free water is absolutely necessary, but draining off the last of the water makes the harvest much safer if the soil is very heavy or the crop late.

If the crop is very early there is less danger of a wet harvest, but more danger of sun-cracked grain if the watering stops late or the harvest drags. The heavy adobe dries slowly and the drying is not helped by appreciable seepage downward; but it is firmer than lighter soil when partly but not thoroughly dry. The Japanese varieties grown in California are typically deep-water rice. French rice and varieties of the Piedmont type in general are less subject to lowering of the yield by early de-watering, because they continue better to fill and ripen when no longer flooded. The draining of the several checks when done must be thorough. Wherever this is not accomplished by opening the gates, the dikes should be cut at once. Pools remaining in the field delay the drying of the neighbourhood, besides seriously interfering with the harvest of the spots themselves.

The month before harvest is the easiest of the season, and should see all machinery put in thoroughly good order, all supplies likely to be needed on the ground, and all help for the harvest certainly at call. The harvest

itself is the evil season of the California rice grower even if everything runs smoothly; delays and extra work while repairs are made make it still more strenuous and expensive, and should be avoided by the most perfect preparation.

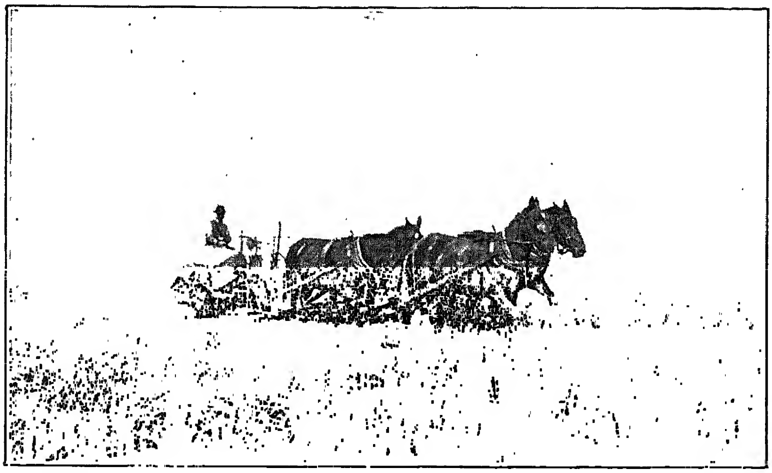
The rice is cut with binders, either ordinary grain binders or imperfect modifications of them. Rice-binding is much harder on these machines than binding dry grain, both because rice is much heavier and because a large part of the work is done on soft ground. No grower dares wait until his ground is really hard before beginning. If the season is favourable it hardens after a few days. In bad seasons rain keeps it soft, and the strain is very heavy on binders, motive power, and personnel. Because the strain on binders in rice is greater than they are usually made to stand, they require particular care, first to keep them running at all, and then to keep them running well. In fields where several binders are working a "trouble-shooter" is employed, whose sole business is to keep the binders working well. He may be paid double the wage of drivers and be worth much more than his hire.

The binders are usually so adjusted that twenty bundles will yield about one sack of rice. The bundles must not be too loose nor tied too near the base or the shocks will not stand; nor too tight else the rice will not dry properly. Almost all of the binders in use are six feet wide. Such a machine can cut an acre an hour. In good seasons an average of five acres a day shows excellent management; in bad seasons such an average is impossible. Several years ago one binder to every seventy acres was considered adequate equipment, and the effective life of a binder averaged hardly more than three seasons. The feeling now is that a binder to every fifty acres is decidedly safer equipment. For this reason, as well as because the newer machines are somewhat better and they receive better care, they last longer. Still, the annual depreciation of binders amounts to about a dollar an acre.

The binders are usually pulled by horses. Some mules are used, but they are less fit for work on soft ground. Light tractors are coming into more general use each year. On really muddy ground horses must be used. For work on muddy ground, where the bull-wheel of the binder would slip, and for work in exceedingly heavy rice, where the common binding mechanism could not handle it, binders are provided with auxiliary engines. This makes them materially heavier, but, still, easier to pull, because the horses do not furnish power to do the binding. Every ranch of any size has a part of its binders thus equipped. On hard ground and in ordinary rice, auxiliary engines are not wanted. They shorten the life of the binder and cut less acres per diem because stops are more frequent.

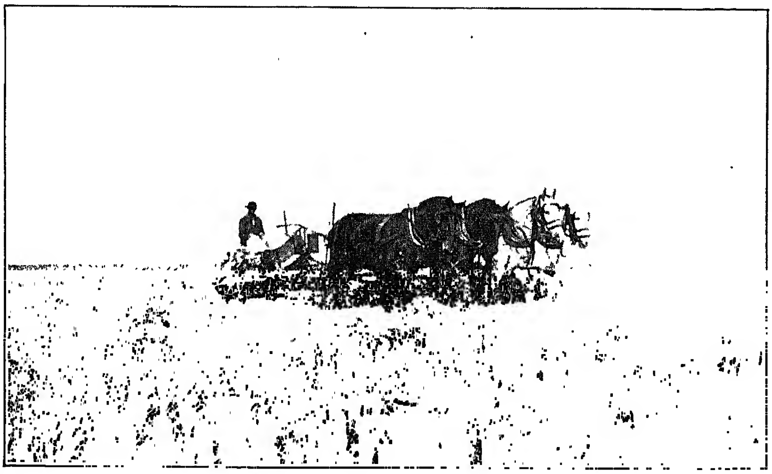
Tractors have been made and fitted particularly for pulling binders, and several have been combined with binders, carrying the latter and sometimes driving their mechanism. Combined harvesters have been used on very early rice and on rice left out through the rains. But growers do not dare to attempt to wait until such machines can work on rice ground; and the quality of the rice would almost certainly suffer even if the weather did not punish such a practice. There have been recent experiments with machines intended to shred or strip instead of to bind rice; but even if such machines are perfected and can be used, they will probably harvest rice of inferior quality.

Binding is at best a very wasteful practice. Leaving out of account cases in which exceptional muddiness increases the loss, estimates of the usual waste are from 5 to 12 per cent. This is partly by shattering, partly by the tramping of bundles and standing rice by stock, partly by skips, partly sometimes by imperfect binding of the rice cut. Most of all, unless the checks are very large, it is by the knocking down of rice by the stock and binders in "opening" the checks—cutting the first swath in each check. Shattering is kept down by growing tight varieties and harvesting promptly.



BINDING WITH STOCK STRUNG OUT.

Photo by Silayan.



BINDING WITH HORSES ABREAST.

Photo by Silayan.

To face page 192.

The care required to keep down the waste by tramping, skips, and imperfect binding is obvious. A variety of efforts are made to lessen the loss in opening the checks. The corners are often cut and tied by hand in advance of binding. Another device to obviate the particular waste in the corners and promote the drying of the field is to cut down the ends of the dikes and run the binder twice around the whole field before opening the several checks. Some growers cut the back-swath first and put the bundles on the dikes by hand. Others, especially if the rice is poor next to the dikes, drive there for the opening round, so that the bundles fall approximately on the dikes. Even then, if the first swath is near enough to the dike so that one back-swath will be enough, the bundles are likely to fall in the adjacent check. Bundles must not be allowed to lie for any time on uncut rice or it will not stand up again after they are removed, and repeatedly moving them is of course expensive. With the ordinary equipment, if the work is going on expeditiously, the most satisfactory practice is probably to open the check as last described and go right ahead with the binding of the check; and then, as soon as there is ample room, to shock the bundles the first time they are touched. It is very poor practice to let bundles lying on the ground delay the cutting of the back-swath, and so make the rice of that swath several days behind in drying and curing.

A binder pushed instead of pulled, and operated without a bull-wheel which must run in uncut grain, is the obvious means of minimizing waste in the opening round. Several such machines have been made but none has been widely used. I have opened a part or nearly all of the checks with one of them for the past six years, but it is far from perfect. Under favourable ground conditions, and in checks of ordinary size, it may save three sacks of grain to the acre. But these are heavy machines, carrying the binder and its counterpoise besides the weight of the tractor itself; and the

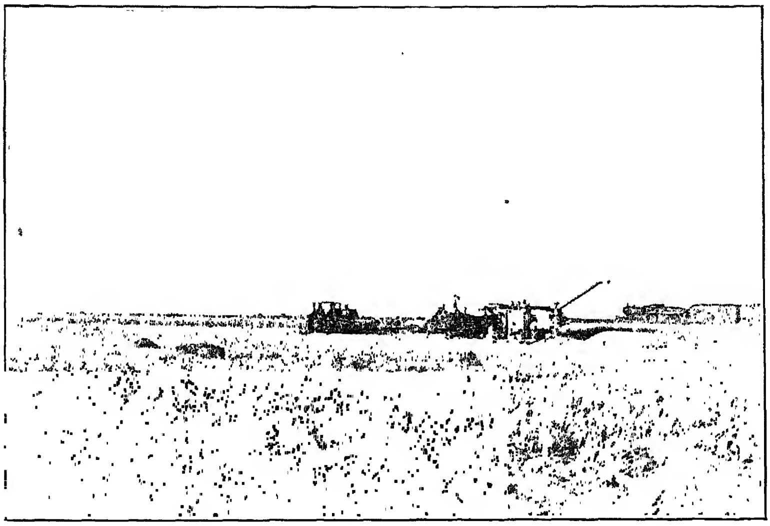
opening swath, preceding the other binding, must be made on soft ground if any ground is soft. Better machines of this kind will probably be made in the near future.

The bundles must be shocked, because they are cut before either the grain or the straw is dry enough to permit threshing. When the rice remains standing until it is dry enough to thresh, which happens only because the grower is unable to bind it, it usually sun-cracks badly. This would be an objection to the use of strippers and combined harvesters for very early rice. Shocking is done either on contract by the acre or by labour paid by the day. The general experience is that the latter is more expensive, but otherwise more satisfactory if small shocks are wanted.

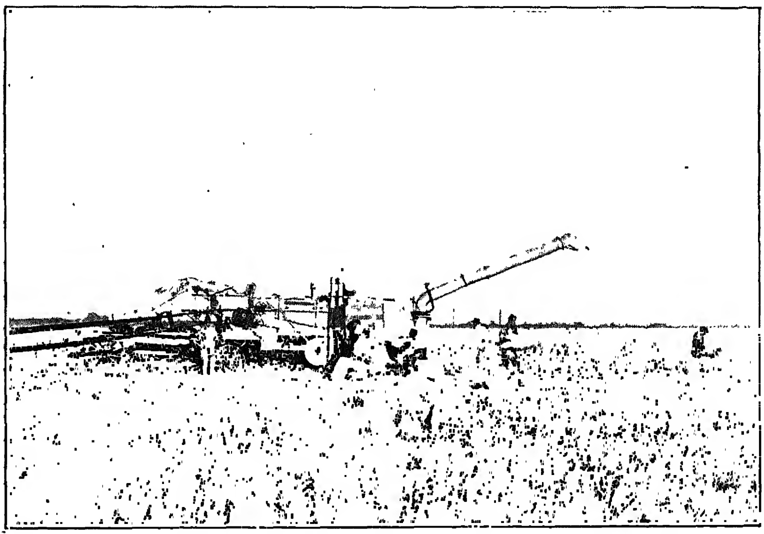
The advice of the Government bulletins is that

> In building a shock, the first two bundles should have the butts firmly set into the stubble and sufficiently apart to be well braced when the heads are brought together. About these set up from eight to ten bundles in such a manner as to form a round shock, making provision at the same time for free circulation of the air. Select a large bundle to serve as a cap. Slip its band down to the heads and put it in an upright position with the heads down and in contact with the heads of the bundles forming the shock. When it is in this position open the bundle from the centre by bending the straw at the band. Pull down the straw and spread it evenly to make a covering for the heads of the cap bundle and the underlying bundles. The grain is not exposed in such a shock and is well protected from rain and sun. . . . During dry weather the process of curing requires at least two weeks. When the crop is weedy and the weather rainy this period is considerably prolonged.

The general California practice is to try to make smaller shocks and not to cap them. The large capped shocks provide conditions for good curing. The local practice aims at quick drying. It has no chance of producing rice as well cured as may be obtained by the use of the larger capped shocks. In this connection, it may be noted that throughout the Orient it is the usual practice to let rice stand in stacks for at least a month



THRESHING, CAPPED SHOCKS IN THE FOREGROUND.

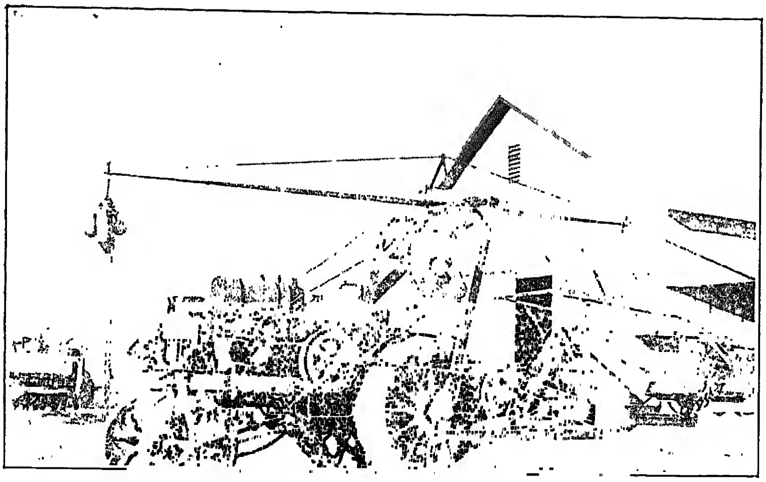


SEPARATOR AT WORK, BUNDLE-WAGON REMOVED BETWEEN CAMERA AND SEPARATOR.

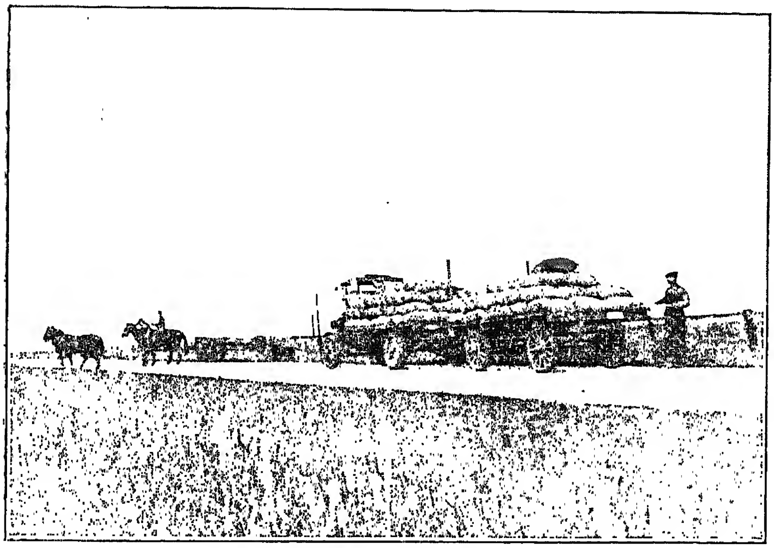
To face page 194.

places them that the load will be secure and easily unloaded. At the separator, if work is going fast, spike pitchers help the drivers to feed the bundles in as fast as the machine can handle them. There are some modifications fitting machines to this particular use, but the most of the separators used in the rice are those made for other grain. That most of them are not used in other grain in season is because almost all of the dry grain of the Sacramento Valley is handled with combined harvesters. From the separator the sacks are piled on beds of straw. With the least possible delay they are taken by banking-out wagons to the roadside, and thence by truck to the warehouse. This procedure is, of course, modified to suit local convenience; for example, wagons haul to the warehouse if the haul is short, and trucks load from the thresher stacks if, as is very unusual, the ground will support them. Some grain goes directly to the mills.

At the warehouse the grain is weighed, and then, as a rule, piled, in piles often of many thousand sacks. The warehouse receipts, showing in-weights, are collateral, on which the growers can borrow. This enables them to hold their rice for a reasonable time for a favourable market. The in-weights are also the basis of the warehouse charges, for the payment of the trucking, and usually for the payment for contract threshing. The sacks weigh roundly one hundred pounds each, net. If the jigger does his work well and the rice is clean, they weigh a few pounds more than this. Awned rice weighs less; "1564" or *Butte* is the only awned rice in the valley, and it is not extensively grown. Chaffy rice weighs less. And poor jigging may make any rice weigh less. This is the temptation of the contract thresher paid by the number of sacks instead of by weight; it wastes sacks for the grower, and may prejudice the buyer. Hulling of much grain by the separator makes the sacks heavier. The separator adjustment aimed at is one which completely separates the grain from the straw, and breaks or hulls as little grain as possible. If



THE PUSH-BINDER.



TRUCK, LOADED FROM BANKING-OUT WAGON.

To face page 196.

the rice is dry and not sun-cracked, these aims can be attained very satisfactorily.

When the rice is once in the warehouse, too many growers consider their cares at an end. In some years, as 1917 and 1919, it has been safe to leave it unseen. The larger part of it probably went through a sweat, was soft for a time, and then hardened again, losing one or two per cent in weight. In 1918 and 1920 there was much deterioration and loss of rice in the warehouses, a considerable part of which might have been prevented; and there has been a considerable loss of the 1922 crop in the same manner. Uncured rice may be expected to sweat in the warehouse, however dry it goes in, but it comes through the sweat without damage if properly dry. Rice with a moisture content of 16 to 18 per cent may likewise not spoil during the winter months, but in great piles it will maintain its moisture content, and even increase it. In bulk in bins it spoils very quickly. During a wet harvest some sacks are likely to reach the warehouse with 20 per cent or more of water. These may be expected to heat before long if piled, releasing still more water, and starting a similar fermentation in adjacent sacks. The damage from such a point of beginning spreads chiefly upward, in the shape of an inverted cone, to the top of the pile.

The business of the grower, if he sends individual wet sacks to the warehouse at all, is to see to it personally that they do not get piled. If his rice as a whole is dangerously wet, it should be "dumped up" not more than five sacks deep, or, better yet, stood on end on the floor. Partially filled sacks turned over occasionally are safer than full ones. If space is not available for such storing, the piles may still be so built that air will circulate freely through them and reach all sacks, which will prevent damage if the rice is only moderately damp.

There has not been sufficient study of the subject to make it possible to define a dangerous degree of moisture, which at any rate will be a function of the prevailing

temperature and atmospheric humidity, care of ventilation and variety and degree of curing of the rice, as well as of its absolute moisture content. Finished rice for export cannot get a Government certificate of grade if it contains more than 14·5 per cent of moisture. The percentage of moisture in polished rice is about the same as in the rough rice or paddy from which it was milled; brown rice is more moist than the paddy or polished rice. Most California rice mills best with 14 to 15 per cent of moisture. Very numerous determinations of moisture in the 1922 crop, by the growers' association, should provide fuller information when the rice is marketed and milled. The Chico High School has also made determinations for the guidance of local growers as to moisture content and rate of drying. *Caloro* paddy is in moisture equilibrium with a saturated atmosphere when its moisture content is about 16·4 per cent.[1] During January 1923 no rice warehoused with more than this amount of water dried out to this point, but during the same time no rice under observation containing less than 18 per cent of water showed damage. When the weather cleared, near the end of January, sacks on the outside of a pile dried in ten days from 17·2 per cent to 16·1 per cent, and to 16·6 per cent four sacks from the top of the pile. In another two weeks it dried to 15·1 per cent on the outside, and 15·6 per cent four sacks deep. It is very important that warehouses be opened as widely as possible on every clear day. And every grower should inspect his rice from time to time to see if the piles need to be torn down.

From the time that rice-growing assumed importance in California, a large part of the growers have been organized for co-operative selling, first as the Pacific Rice Growers' Association, and, since a reorganization in 1921, as the Rice Growers' Association of California. Of the 1922 crop, the association has controlled about 60 per cent of the crop. While its sole explicit function

[1] Information by Dr. F. T. M'Lean.

is marketing, it undertakes to help its members with advice and information whenever it can. The most important service of the new organization has been the financial support of the industry by facilitating loans of Government money. Without this support any attempt at orderly marketing would have been futile, and the industry would have been very slow to recover after the loss of crop and collapse of market in 1920.

The rough rice is almost all sold to California mills, of which there are fourteen—more than the present production can keep in full operation. It does not fall within the scope of this work to follow the rice in great detail after it leaves the hands of the producer, except as its subsequent fate is of real interest to the producer. The defects in quality of rice, as the mills encounter them, have such interest very clearly, because they influence its value. In some seasons the chief defect is excessive moisture, in others excessive sun-cracking. The moisture is a function of the weather during harvest and of the imperfect curing. Of the latter, enough may have been said. As to the former, a recapitulation is worth while for the sake of emphasis. The grower cannot control or foresee the time of the rain. But he can minimize the damage to his crop:

1. By early preparation of his ground and planting, and hurrying the first irrigation; two weeks' start in the spring hastens the crop by a few days.

2. By ceasing to irrigate at the earliest safe date; several days' average gain by the valley as a whole would improve the quality as well as hasten the crop.

3. By losing no time in the harvest; probably an average of a week is lost by inadequate and imperfect equipment and preparation, by not being ready each week for the next week's work.

4. By greater care not to thresh wet rice or let sacked rice become wet.

5. By care of damp rice after the harvest; there has been much unnecessary loss for want of this care.

6. Most of all, by growing rice of early varieties.

How critically important this matter of moisture is to the grower has been amply demonstrated by the 1922 crop. If all of it had been fit to market immediately after the harvest, all of it could probably have been sold at a reasonable profit. Because it was not fit, much of it was raised at a substantial loss, and the profit or loss on the crop as a whole remains problematical.

Sun-cracking, as the word indicates, is a fine, crosswise cracking of the grain, typically due to exposure to the sun and rapid drying. The effect is that an excessive proportion of the grains break in milling. As the chief element in fixing the value of paddy is the amount of "head rice" (whole grains) which can be milled out of it, its value decreases rapidly with the presence of grain which will break. Early rice is much more subject to sun-cracking than is late rice. It therefore requires particular care, to stop irrigating in due time and proceed promptly with the harvest. It may be worth while to cap the shocks of early varieties, if not of late rice. The presence of superficially green grains does not lower the value, as long as they are plump, "well filled"; a crop containing them usually shows little sun-cracking, and the green layer mills off easily. Chalky grains are a real defect, ascribed to unequal ripening, but not well understood. Dirt in rice is not a rare defect, though the means of avoiding it by care are obvious. The presence of foreign seed, chiefly of the grasses, is a very common defect; the field treatment for avoiding it has been explained. An attachment to the separator is sometimes used to remove excessive water grass seed.

Cost of Production.—As California is the typical example of the use of machinery in rice, and there is everywhere a desire to save hand work by the use of machinery, a brief statement of the cost of California operations is of interest. It will of course be understood that these costs as listed are only approximate, that they vary greatly from year to year, and that the history of rice in California has fallen in a time remarkable for wide fluctuations in all costs and prices. The

figures given may be construed as of 1922. In 1915 they were lower. In 1920 they were about 60 per cent higher.

Land which has been in rice is worth forty to one hundred dollars an acre, depending upon demonstrated fertility, certainty and cost of water and ease and freedom of drainage, ease of operation and accessibility to warehouse or market. The cost of ditches for irrigation and drainage is too local a question to permit general estimates. The cost of buildings can likewise not be estimated in general, because of the range of quality. Running the contours costs twenty to thirty cents an acre; putting up dikes, fifty cents to a dollar; gates in the dikes, twenty to fifty cents. Except for repairs and depreciation, these may not be items of annual expense, and the value given to old land presumes their presence and need of repair. The direct annual cost of the crop may be tabulated approximately as follows:

Ploughing	$3.00	to	$4.00
Additional cultivation	1.50	,,	2.00
Repair of dikes and gates	.20	,,	.20
Seed	2.75	,,	3.25
Seeding	.20	,,	.50
Care of growing crop	3.00	,,	3.00
Weeding	..		..
Water	6.00	,,	7.00
Binding	3.00	,,	6.00
Binder twine	.55	,,	.70
Shocking	1.00	,,	1.50
	$21.20	,,	$28.15
Cost per sack of 20 sacks	$1.06	to	$1.41
,, ,, 30 ,,	.71	,,	.94
Threshing, per sack	.20	,,	.45
Sacks	.10	,,	.10
Sack twine	.01	,,	.01
Banking out	.02	,,	.03
Trucking	.05	,,	.10
Warehousing	.10	,,	.10
Cost per sack, warehoused	$1.54	,,	$2.20 for a 20 sack crop.
,, ,,	1.19	,,	1.73 ,, 30 ,,

To this cost must be added taxes, depreciation, and overhead, all of which vary widely, and may be estimated collectively at $4.50 to $9.50 an acre; or, per sack of a 20-sack crop, 22 to 48 cents; of a 30-sack crop, 15 to 32 cents; making the total cost of a 20-sack crop $1.76 to $2.68 per sack, and of a 30-sack crop $1.34 to $2.05 per sack.

In the absence of especial difficulty, such as is presented by prolonged bad weather, the going contract price of threshing in 1922 was 25 cents a sack; this includes collecting the rice as it stands in shocks and piling the sacks by the separator. Using this figure, and the maxima above for all other operating expenses, and $3.00 for taxes, the total of these items is $48.85 per acre, or a cash outlay of $1.63 per sack of a 30-sack crop. While individual maxima in this table are sometimes exceeded, no grower is likely to reach all of them, and many growers get below some of the minima given above. On the other hand, depreciation is real, whether or not felt at the time; it is impossible to eliminate all overhead; and there are omitted from these figures insurance, the association charge of five cents a sack, and interest. The market price of first-class paddy has ranged since harvest from $3.00 down to $2.05, and it has been a weak market.

A number of conclusions are obvious. Under present California conditions, with wages of common unskilled labour about three dollars and board, the most complete practicable elimination of labour does not make it expedient to raise rice without the expectation of a crop in excess of 20 sacks of paddy. There must be no unavoidable waste if a 30-sack crop is to pay rent for the land or interest on the investment. Crops materially above 30 sacks are quite sure to be profitable. Except under the influence of the bonanza prices of 1919, there has been a steady tendency to operate more economically, and better farming seems to be increasing the average crops from old land. While the calculation above, based on the assumption of

rather low yields, shows a low margin of probable profit, the real weakness of California rice-growing as an industry does not lie here, because it can well stand the elimination of lands and growers incapable of producing good crops; it lies in the danger of loss of crops due to bad harvest weather.

MEANS OF IMPROVEMENT

Early Varieties.—The most outstanding want of the California rice industry is obviously an earlier and therefore safer harvest. There is no probability that any very early rice will yield maximum crops. But rice which will yield, with proper handling, a really profitable crop, mature early enough to be bound in September, certainly exists. There has been too little attention to early varieties on a field scale to make it clear which of those already grown are most certain to pay. *Onzen* has not yielded well for most growers; *Eureka* lodges too badly; *French* has had only one real field test. New pure strains should in the near future be better than any of these. But even with *Onzen* or *French* as the best available, the grower of a considerable acreage who plants only late rice courts disaster needlessly. For the valley as a whole to continue to seek the highest possible returns by sticking as exclusively as it has done to the general type of *wataribune,* however productive it is and however fine its quality, risks practical extinction of the local rice business. For no financial support can be found to revive it, if it suffers another such catastrophe as the loss of the 1920 crop.

Markets.—There is always a market at some price for rice. The collapse of exchange and loss of purchasing power of many normally rice-importing countries have naturally made this price low during the business depression after the war. Japan felt the slump later than most countries, and was able to buy about 90 per cent of the California crop of 1921. Such complete marketing in one place results in the loss of any other

markets which may have existed; and no crop dependent on one market, and that a foreign one, is safe. During the most of 1923, Japan, though without a surplus at home, has been unable to pay for California rice a price satisfactory to mills and growers. Spanish-speaking countries, as a whole, are like Japan in preferring this type of rice, but trade connections with most of them are poor. The United States would seem to be the natural market, but they consume less rice per capita than any other important commercial nation in the world, and have been educated to prefer, for what rice they do consume, the long-grain rice of the Gulf states. The cultivation of a home market for the type of rice grown in California is a necessity if the industry is to escape or outgrow the danger of loss due exclusively to economic conditions abroad. In particular, it behoves those interested in the California rice business to acquaint the American people with brown rice, an article few of them ever saw or heard of, but a cereal at once delicious and remarkably nutritious, which can be marketed at a price below that of ordinary polished rice.

Field Practice.—The more obvious and certain methods of improving field practice have already been discussed, but are recapitulated here for the sake of completeness. The changes required are to make the crop more certain and cheaper, and to keep old land in profitable use. Making it more certain by an earlier harvest has just been discussed. The most important evident feasible way of cheapening it, by the acre, by using water to hold the weeds in check, is each year coming into more general use. Cultivation is better, on the whole, each year, which cheapens the rice by the sack. There is a clear field for economy by the elimination of waste, especially by the use of satisfactory push-binders.

Smaller Holdings.—The California rice industry needs more men engaged in the business of growing rice, not to expand it, but to cut the large ranches into farms of

such size that their owners can work them themselves. Experience has shown that this is decidedly a more certainly remunerative business for the man with eighty acres than for the man or company with eight hundred or eight thousand acres. The general appreciation of this fact is the greatest improvement in sight for this industry in this valley. Through its bonanza years rice-growing resulted in an increased average size of land holdings, where they were already far too large, and in an influx of Chinese, East Indian, and Japanese skilled rice-growers, chiefly as tenants. For both of these reasons there arose much popular prejudice against the business. It was charged that white men could not live in rice country; and particularly that, in a land where malaria is endemic, rice was responsible. The United States Health Service sent a party to try to remedy the imaginary evil, and found the solid rice country the most malaria-free part of the valley. Foreign tenants are becoming few, and there is a most welcome tendency for the great holdings to be divided into farms where families have their homes.

Miscellaneous.—Being a new industry, rice-growing in California has not fallen into grooves of custom, and all sorts of schemes for improvement are constantly being advanced. The stripper is an example, as are the various attempts to make push-binders, attempted economy by disking instead of ploughing, etc. Sacks are a very material item of expense, and bulk storage has been proposed as a means of escaping it. Only very thoroughly dry and well-cured rice is safe in large bins, and only perfectly uniform rice can be mixed. It may be practicable and well worth while to dry rice artificially on a large scale and thus salvage a damp harvest. Wheat is said to maintain an excellent quality after rapid artificial drying. There has been a pretence of drying rice in California; but it was too farcical to let the general idea be discredited because a large part of the rice under treatment was spoiled. There are several schemes for increasing the revenue of the grower

by the utilization of by-products; these will be taken up later.

Because the idea has prevailed that the fouling of the land by water grass made it necessary to lay it out of rice for a time, there has been a considerable effort to find a profitable crop to raise in alternation with rice. A crop to be irrigated and cultivated while growing is particularly desired. No such crop has so far proved really satisfactory. The grain sorghums and broom corn have been the most promising, but are hard to handle well on a large scale, and must be harvested with considerable labour just when the rice harvest demands every available effort. Cotton was given an extensive trial one year, but it cannot pay California wages for the harvest. Cowpeas, soy beans, and sesame can be grown on rice land, but are not recognized California crops. Wheat and barley produce better after rice than on the same land, worn out for them, before it produces rice. But the seasons are such that the land has to lie fallow a summer between the rice and the dry grain. The Italian scheme of sowing wheat on the muddy ground immediately before the rice harvest has never been tried here. Up to the present no loss of fertility of the land itself has seemed to demand an alternation of crops. It must be expected to do this in time, and a more careful study of possibly available crops will then be necessary.

It has likewise not been shown up to the present that any fertilizer except barn manure can be applied here with profit—a condition which of course will not continue indefinitely.

California is peculiar again in that there is no evident general present field for the improvement of the rice industry by financial support. This is of course not because the growers do not want more money, or could not do their work better with more means. What is meant is that in general the growers are extended credit to the full extent that is justified by their prospect of being able to repay their loans. The

industry grows stronger in this respect as the farms become smaller, and the personal efforts of the farmers, applied to the crops, become in greater measure one of its chief assets.

CAROLINA

The accepted account of the introduction of rice into South Carolina is that a ship from Madagascar to England, having rice in its cargo, was blown out of its course, and put into Charleston in 1694. The governor of the colony had lived in the East, knew rice as a growing crop, recognized the fitness of the local conditions, and secured some seed from the captain of the ship. This is credited with being the ancestral stock of *Carolina white* rice. Immediately afterward, a considerable shipment of seed was made from England. The rice industry was established, and exportation began with remarkable quickness. From that time up to the Civil War, Carolina rice was an appreciable factor in the small rice trade of those days, and was firmly established as the world's highest standard in quality.

The industry spread to the neighbouring colonies, afterward states, Georgia having second place and North Carolina third, while rice remained an important crop of the Atlantic seaboard. The Civil War almost killed the industry, and it has never recovered a position of great importance in this region. Even now, however, more than sixty years after Carolina rice ceased to be a factor in the markets, it retains its prestige, like Mocha coffee, and in many places the finest rice available still sells under this name. *Gold seed* was a later introduction, and, if possible, of still finer quality. Carolina rice was effectively introduced into Java half a century ago, and has since been an article of export thence. At about the same time, diligent attempts were made without success to establish it in India.[1] It may be the *Huê-ky* of Indo-China; the descriptions do not

[1] Simmonds, P. L., *Tropical Agriculture*, 1875, p. 319.

tally very well, but the latter is described as awnless, and *Carolina white* has less tendency than *Honduras* to produce awns.

The principal and typical rice region of Carolina was, and is, that in which the water of the rivers rises and falls with the tide. The fields were leveed against the streams, so that they could be irrigated at high tide and drained at low tide. The land is so low that it is practically impossible to cultivate it dry. Most harvesting machinery had not been invented in the great days of Carolina rice, but the lowness of the old rice lands effectively bars its use there, and the re-establishment of the rice industry by its use, now. Transplanting was not practised in Carolina, but the harvest was by hand, which was the chief bar to the recovery of rice after the abolition of slavery. Rice culture naturally spread from the coastal flats to higher land, where it was irrigated in such ways as are usual elsewhere; but in such places it was in competition with other crops, and most higher soils in that region are not heavy enough to give rice any advantage. It was also widely planted, but on a small scale, as an unirrigated crop, but the yields without irrigation do not make it profitable, nor is the quality satisfactory.

THE GULF STATES

Some rice has been raised in the Mississippi delta region for more than a century. During and after the Civil War, rice-growing increased slowly in this district, but did not reach 50,000 acres before 1880, and has never reached 100,000 acres. The soil is a rich, heavy silt, irrigated by water siphoned from the river, the level of which, during at least a part of the year, is above that of the fields; it is suited to other crops as well as to rice, and is less peculiarly suited to rice culture by typical American methods than is that of the region farther west. This remains the chief district for the culture of *Honduras* rice.

It was in the early 'eighties that the possibility

of raising rice on the prairie lands of south-western Louisiana became known. Settlers from the north soon afterward introduced the mechanical methods already familiar in handling wheat, and there began in 1884 a boom very like that of thirty years later in California, during which it was common for the first crop to pay for the land and equipment. Several good years were followed by a series of poor ones, marked by poor yields due to lack of water, with a resultant cessation of expansion. Another boom began in 1896, with the construction of canals and the provision of sure water. As more of these were put in and more land served, the growth of the industry was fairly steady and rapid up to the War years. Since that time, as in California, the area planted each year has depended upon the profit from the preceding crop.

The following tables show the area planted, and the crops, since 1914, in all states having any real rice industry:

AREA IN THOUSANDS OF ACRES

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	1923.
S. Carolina .	7	4	3·5	3	4·5	4	7	7	8	..
Georgia . .	1	1	0·8	1	1	1	4	3	3	..
Florida . .	0·4	0·5	0·7	0.8	1	2	3	4	3	..
Mississippi .	1	2	2	2	3	3	3	1	1	..
Louisiana .	337	401	443	500	580	560	700	480	555	482
Texas . .	240	260	235	230	245	218	281	166	191	150
Arkansas .	93	100	125	146	170	158	175	125	154	136
California .	15	34	55	80	106	142	162	135	140	112

YIELD IN THOUSANDS OF BUSHELS

	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.
S. Carolina	179	90	49	75	104	90	175	175	208
Georgia .	31	20	16	27	31	29	104	78	72
Florida .	10	12	18	21	29	42	72	88	75
Mississippi	30	45	53	63	69	95	93	20	19
Louisiana	10,802	13,714	20,392	18,250	17,980	19,712	25,200	17,280	19,980
Texas .	8,102	7,930	10,575	6,210	7,840	6,998	9,534	5,993	5,959
Arkansas	3,685	4,840	6,312	5,994	7,310	6,162	8,575	6,688	7,392
California	800	2,268	3,263	5,600	7,011	7,881	8,262	7,290	8,260

These tables are compiled from the year-books of the U.S. Department of Agriculture, except the estimated acreages for 1923, which are from the preliminary estimate by the Rice Millers' Association. The bushel is 45 lb. of rough rice.

The climate of this rice region is less extreme in various respects than that of the valley of California. The warm season is longer, the nights are warmer, the days not so extremely hot, and the air quite humid, with occasional rain at all seasons. The average rainfall varies from 47·6 inches in the western edge of the rice district in Texas, to 52·05 inches in Arkansas, and 54·6 inches in Louisiana, in all places well distributed throughout the year.[1] The rain provides a part of the water for the growing crop, so that less has to be supplied artificially. And, on equally heavy soil, less is required here than in California because less evaporates. Rain often impedes the harvest, but does not make it impossible, as it may in California.

The typical prairie rice soil of Louisiana and Arkansas is a heavy loam "containing approximately 4 per cent of very fine sand, 69 per cent of silt, and 23 per cent of clay. The very impervious subsoil lies at an average depth of about 16 inches." The Texas soils are still more clayey, and therefore harder to work. The heaviest of all soils in the region is called "hogwallow." This and the other clay lands are regarded as better than the silt for rice production.[2]

The rice experiment station at Crowley, Louisiana, was established in 1909. The United States and the state co-operate in maintaining it, variety tests and selection in particular being in charge of the Federal Government. A vast number of varieties have, of course, been tested there, and a considerable number of these, or selections from them, have come into practical use. Carolina rices were the first grown in Louisiana,

[1] Chambliss, C. E., "Prairie Rice Culture in the United States," U.S.D.A., *Farmers' Bull.* No. 1092, 1920.

[2] Quereau, F. C., "Rice Investigations," *La. Agric. Exp. Stat. Bull.*, No. 172, 1920. This replaces *Bull.* No. 77, 1904, by Dodson, Stubbs, and Browne.

but they have almost disappeared. There followed many years during which *Honduras* was the dominant type, with Japanese varieties in second place. It was during these years, building on the sound record already established with *Carolina*, that Gulf rice earned its very high reputation for quality. *Honduras* is distinctly a fancy rice. It is not a heavy yielder, and it turns out a notably low percentage of head rice in milling. To be remunerative it must therefore sell at a price so high that its market is limited.

To produce a crop marketable with profit on a large scale and in easier competition with other rices, the growers have turned largely to other varieties. The standard ones from Japan have never proved as adapted to the southern conditions as to those in California. *Shinriki* and *wataribune* have been the most grown; the former is too short, and the latter too prone to lodge, on good ground, to bind conveniently and without considerable waste. In recent years the drift has been overwhelmingly to *Blue Rose*, a selection by Mr. Wright, from material found in a field of Japanese rice in 1907. The rice areas in the United States devoted to the several groups of varieties are shown by the following table, compiled by the Rice Millers' Association:

Estimated Acreage in 1923

	Honduras.	Japan.	E. Prolific.	Blue Rose.	Total.
Louisiana	54,868	17,466	28,808	381,224	482,366
Texas	31,039	13,660	28,825	76,465	149,989
Arkansas	17,500	10,280	26,100	82,004	135,884
California	330	111,050	..	125	111,505
Total, U.S.	118,737	152,456	83,733	539,818	894,744
Percentage	13·27	17·04	9·36	60·33	..

In this table, "Honduras" includes *Carolina*, *Fortuna* (the most popular of the Crowley station selections), and any other long-grained varieties. In the "river" and "Teche" parishes of Louisiana these are still favourites,

more than half of the long-grained rice, but less than one-tenth of all rice of the state, being grown there.

Federal and state authorities have freely expressed their misgivings as the *Honduras* gave way to *Blue Rose*, but naturally without much effect while *Blue Rose* was decidedly the more profitable. The Crowley station served various rices, cooked, at the state fair, without names, and asked the consumers to vote for the best in quality; and *Blue Rose* received very few votes. Up to 1920 the prestige of southern rice was such that California growers had to be content with an appreciably lower price; but during the past three years the average California returns per sack have been distinctly the higher. A better marketing organization in California is partly responsible for this change; but the sounder explanation of it, on the whole, is that the bulk of southern rice does not retain its old fancy quality. A people eating a scant 5 lb. per capita per annum, as do the Americans, are not keen judges of it, and may be slow to suspect the quality of anything given them when they ask for Carolina rice. But, to hold their old place on an export market, the southern producers need to grow their best varieties on the largest scale. From 1921 to 1923 there is a marked tendency to return to the better qualities, both *Honduras* and Japanese.

The description of the culture of rice in California has been sufficiently detailed to let that applying to the Gulf states to be brief, and deal chiefly with the differences. In the preparation of the land, the southern grower builds such dikes as the Government has advised, low and broad, made by throwing together a number of furrows. A more specialized method of building them is to use an "A," pulled with the closed sharp end ahead, one side flat against the land side of the last furrow, the other side pushing the soil to the dike. The aim is to construct dikes which will not obstruct the passage of machinery in cultivation or harvest, and will impound a maximum depth of five inches of water. Silt land is ploughed in the fall, wet or dry. The very heavy

soils, like the adobe in California, can be handled only when fairly dry. In building the dikes and in working the land mules are more generally used in the South, while almost all such work is done with tractors in California.

It is the general southern practice to prepare a good and compact seed-bed. A common sequence of operations to this end is to follow the plough with a packer; then to disc two or three times; then to harrow or drag, one to three times; and to finish with the packer. The seed is then drilled well into the ground. Under the climatic conditions the thorough cultivation usually makes the soil hold enough water to germinate the seed, without irrigation for that purpose. Sixty to 70 lb. of seed to the acre is considered sufficient. An average of perhaps 10 per cent of the total area is sown broadcast, but this is considered advisable only when the land happens to be too wet to permit the use of the drill; 80 to 100 lb. are then sown.

Practically all of the water [1] supplied artificially is pumped. Some 300,000 acres are irrigated from wells. This is usually a somewhat more expensive source than the streams and ponds, because of the higher lift; but the difference may be offset by the use of less water, as small systems can be operated in more constant adaptation to the requirements, and the seed-free water from wells may for a time reduce the cost of weeding, or postpone foulness. Given equally impervious soil, which permits very little seepage, the humid climate and occasional rains enable southern rice to thrive with not more than half as much irrigation as is necessary in California —say 2½ feet as against 5 or more. Above a minimum of perhaps 2 feet, which provides for evaporation, transpiration, and the necessary submergence, more is required in direct proportion to the loss by seepage. There are said to be rice-fields which require 38 to 40 gallons per minute—a service of more than a second foot to every nine acres.

[1] Haskell, C. G., "Irrigation Practice in Rice Growing," U.S.D.A., *Farmers' Bull.* No. 673, 1915.

The general practice is to irrigate first about thirty days after seeding, or when the rice is 6 inches high, and to hold this water for about ten days. During the remainder of the growing season water is applied as needed, depending upon weather, soil and weeds, and pests and diseases. In all cases the checks are kept full from the time the rice is coming into boot until it is withdrawn preparatory to the harvest.

Weeds are the bane of the southern rice-grower and usually determine the number of years that land is kept continuously in rice. The worst of them is red rice, a variety (sometimes unreasonably called a species) which has a red pericarp, is early, and shatters badly. The last characteristic enables it to seed the field, progressively from year to year, until its abundance makes it expedient to keep the land out of rice for a time. The vitality of the red rice grain, once encased in mud, is indefinite, there being authentic cases of its living at least twelve years. The method of avoiding infection is to be sure to have none of it in the seed planted. In parts of the Orient, especially India, there are many such varieties, but they are held within bounds by transplanting and by the methods of harvest. There are also many red rices, such as those in much Italian rice, which, however unwelcome in the milled rice, do not behave like weeds in an agronomic sense.

For the control of barn-yard grass and other weeds, with the exception of red rice, the Texas station[1] strongly advises cultivation. In its experiments the seed was drilled, in rows 16 inches apart, using as much seed per acre as is usually used drilling the rows 8 inches or less apart. One cultivation was usually enough, but a second was given if needed. In three tests out of four the yield was greater than in the control plots, planted as usual and not cultivated. Other advantages were economy of water, relative immunity from damage if irrigation had to be delayed, and, especially, a

[1] Laude, H. H., "Control of Weeds in Rice Fields," *Texas Agric. Exp. Stat. Bull.* No. 239, 1918.

freedom from progressive fouling of the land from year to year. The best implements were the weeder (compare the Acme weeder, p. 310) and the spring-tooth cultivator.

Because rain may fall at any time, although there is little danger of the winter-long flooding to which California rice is exposed by delay in harvest, the southern planter is always ready to harvest in the mud if he happens to have to. After the rice is cut he is not compelled, like the Californian, to make haste. He therefore shocks his rice in shocks of greater size, caps them for a measure of protection against sun and rain, and gives the rice two weeks or more in which to cure. His rice may suffer some damage in the field, especially if there be warm and wet weather; but it goes to the warehouse incomparably safer from subsequent damage than it does in California. The paddy rice is sacked in the South in sacks holding 162 to 200 lb. It is measured in Louisiana by the barrel, an hypothetical unit of 162 lb., supposed to yield one "pocket" or sack of 100 lb. of clean rice. In Arkansas, as in United States statistics, the unit is the "bushel," which is 45 lb. of paddy, always by weight, not by measure.

The differences between southern and Californian cultural methods, so far described, depend upon peculiarities of climate, etc. Another occasional distinctive feature, indirectly so permitted, is bulk handling of the paddy. In California paddy is sacked, in the first place, because all grain is so handled—it is the "custom of the country," which has endured while other wheat states have completely abandoned it and replaced their warehouses, where they ever had them, with elevators. But while California wheat and barley might be handled much more economically in bulk, no such change is possible, by itself, in the case of California rice. In the South, after curing in the field, bulk storage is relatively safe, and is practised to some extent; always, however, with provision to dry the grain somewhat if necessary. Only the use of paddy driers, common in Italy, will let

the bulk handling of paddy in the United States become general and safe.

There are other features of the southern rice culture, in process of development rather than well established as yet, which result from the greater age of the industry. These are an alternation of crops, and the use of fertilizers. The moister summer climate and generally lighter surface soil, and cheaper labour, offer a wider opportunity for choice in alternative crops than is evident in California. The propriety of rotation on most prairie soils is well recognized, but particular methods and sequences have not been agreed upon and adopted. Writers in the *Rice Journal* continually list rotation among the necessary immediate modifications of practice, but do not provide the directions. Quereau points out that a long-term rotation is expedient, because of the cost of erecting and removing the dikes, wanted for rice but in the way of other crops. Except for this difficulty, two years of rice alternating with two years of *Lespedeza* forage has worked well. But something like six years of " highland " crops, alternating with a similar period in rice, is more promising. Soy beans and cotton are preferable to corn (maize), because they rid the land of red rice more effectively. Cowpeas are good if cultivated, but not if sown broadcast. The Louisiana station report for 1918–19 reports with especial favour on Biloxi soy beans.

As to fertilizers, the testimony is still quite discordant, which is only natural considering the limited experience, diversity of soil, and unequal time the lands have been in rice. It is evident, however, that the stage has been reached where their general use is much more likely to pay [1] than it is in California. At the Crowley station [2] a series of plots were treated respectively with the same fertilizers from 1910 to 1916. The use of potash paid the first year only, while the use of

[1] Wise, F. B., " Fertilization increases Productivity, etc.," *Rice Journal*, 26. (1923), 11.
[2] *La. Agric. Exp. Stat. Ann. Report*, 1916.

phosphates was profitable during five years. Other experiments seem to agree that the use of acid phosphates can be expected to return a profit. Station experiments throw doubt on the present expediency of liming and on the use of cyanamide. The use of stable manure and of cotton-seed meal paid with *Honduras*, but not evidently with other rice.

There remain certain features of southern rice culture associated with economic weakness as compared with California. This is not intended to say or imply that rice culture is less profitable in the south; it could, indeed, be made to appear so by statistics, but these take no account of the loss of virginity of new land where the industry is newer. But no southern state has the economic strength, general or agricultural, of California. The lower wages and smaller areas handled as units, however owned, in the south, although functions of relative poorness, may well tend to make rice culture more profitable. Tenant-farming is far more general in Louisiana and Texas than in California, except as in California it has been increased by the operations of Orientals, who work here in a most un-Oriental manner on a large scale and usually with ample means, but cannot legally own land. In Louisiana and Texas much land is owned by canal companies, and water as well as rent of land may be paid for by a share of the crop. The effect is that the average actual producer of rice in the south raises his crop with a comparatively small investment of cash in his crop. This blunts the effects of bad years, but makes any control of their marketing by the growers more difficult, and is really a cause as well as a symptom of relative economic weakness.

In addition to the difficulty in co-operative marketing entailed by this kind of tenantry, the southern growers have at present two co-operative organizations where one could cover the field with much better prospect of effectiveness. On the other hand, the southern mills are well organized. Growers are too

likely to recognize strength in such an organization only as it is one of buyers of paddy, and to forget that it also sells rice, and that some organization strong enough to find and hold markets, and ascertain and meet their demands, is essential to the prosperity of the whole industry.

CHAPTER VI

RICE IN THE PHILIPPINES

Because of the author's personal familiarity with Philippine rice, and because there are more complete Philippine Governmental studies of the subject than have been made in the neighbouring countries with like low production per acre, and these studies provide a sound basis for discussion of the means of improvement, the rice-growing in the Philippines will be described as an example of general Oriental practice. The Philippines differ from most neighbouring lands in producing less rice than is locally consumed and might easily be produced. Still, rice is incomparably the most important insular crop; and is raised by the same methods used in every Oriental land which produces it on a greater scale.

Official statistics on Philippine rice production are shown in the following table :

Year ending June 30.	Area in Rice, in Hectares.	Production of Rough Rice.	
		Total, in Kilograms.	Average per Hectare in Cavans.
1909	1,156,105	747,942,688	15·05
1910	1,192,141	810,940,698	15·82
1911	1,043,757	882,794,128	19·67
1912	1,078,891	499,766,124	10·77
1913	1,141,242	1,053,450,894	21·47
1914	1,244,937	977,683,002	18·26
1915	1,130,713	766,195,113	15·75
1916	1,140,829	897,791,152	18·30
1917	1,225,692	1,215,898,831	23·07
1918	1,368,140	1,539,186,978	26·16
1919	1,381,339	1,452,610,907	24·45
1920	1,484,895	1,584,154,028	24·48
1921	1,661,430	1,808,464,300	24·79
1922	1,673,380	1,893,845,800	26·14

There has been a fairly steady increase in production. This has been more rapid than the increase in population, which is a little more than ten million. There is every year some rice imported, mostly from Saigon. Rice is grown in every province, but the big production is in provinces with marked wet and dry seasons.

Instead of the familiar two cultural methods, upland and lowland, the Bureau of Agriculture[1] recognizes four —clearing or *caingin,* upland or *secano, sabog* or broadcasting on paddy land, and typical lowland.

The first of these, primitive in a sense although not probably the most ancient, and practised by widely scattered hill people from India across Malaya, is the planting of forest clearings, called *caingins* in the Philippines. Until a decade ago the making of clearings in the public forest was very common, but has now been largely suppressed, partly to protect the forest, but chiefly to limit the extension of grass lands. The *cainginero* clears and burns over the land during the dry season and plants it when the rains begin. Typically, there is no cultivation at all. Holes are punched in the ground with a stick and the seed is dropped in and covered. The planting may be individual or community enterprise ; in the latter case it is an important festival. Music may be furnished for the planters, or they may make their own, much louder. The Bagobos, in Mindanao, advance in a line across the field, each driving holes and stirring the ground with the sharp lower end of a long bamboo, the split upper end of which makes a resounding clack at each drive, keeping the time and letting the denizens of the woods for miles around know that this is the day the rice is planted.

The first crop of the caingin, if the ceremonies are effective, is very heavy, the next is not nearly so good, and a third may or may not be planted, but at best will be poor. In the absence of fire the land returns to brush and then to forest, unless cleared again before it

[1] Camus, J. S., "Rice in the Philippines," *Phil. Agric. Rev.*, 14. (1920), 7-86.

reaches that stage. The Government's chief objection to the caingin practice is that, by accident or intent, fire after the clearing is abandoned very often turns the site to grass instead of forest. Some caingin rice is delicious, and this is hardly purchasable; most of it is rather inferior.

The typical upland or secano method differs essentially from the preceding in that the land is ploughed. Seeding is usually broadcast, but sometimes in (not with) drills. The drill is then a furrow into which the seed is dropped by hand. The average yield of upland is considerably less than that of paddy rice, both because it is more exposed to various dangers, especially drought, and because at best this method does not provide the most natural conditions for rice. However, pure-line selection from good varieties has yielded surprising results, the crops exceeding 115-fold.

The outstandingly costly feature of upland rice culture is the weeding. The weeds are not of any particular kind, and so demand no specific treatment. They are simply the prevalent weeds of the locality. The worst, because the commonest, least conspicuous in rice, and its worst competitors, being its relatives, are the grasses, particularly the ubiquitous *cogon*, *Imperata*, *alang alang* in Malay. If the seed is sown broadcast, as is usual, pulling by hand is the only possible method of fighting weeds. This work is almost never paid for in cash. It may be paid for from the crop. Very commonly a group of neighbours work together, men, women, and children, going from field to field.

The early rice study of the Philippine College of Agriculture was all with upland cultures. Wages ran from 30 to 40 cents a day or 5 cents an hour, American money, and no crop grown was worth the cost of producing it. This was tolerable in experimental cultures but raised misgivings as to the economic status of the industry. Records were then kept on the operations of a number of neighbours, with the result that most of them showed a loss if the labour on them was

valued at $2\frac{1}{2}$ cents an hour. At this rate the best that could be said for upland rice was that it gave the family a job. Later studies have shown results economically somewhat better in other years, the study of Ramos [1] leading him to conclude that there is a lesser cost per acre for upland rice, sufficient to make it more likely than lowland to yield a profit to the tenants—the landlord always making some profit. Camus's estimates of cost of production (*l.c.* p. 40) are that upland rice costs 65.20 pesos (half-dollars) per hectare, or 3.26 pesos per cavan, as against 84.20 pesos per hectare, or 2.63 pesos per cavan for lowland rice.

Another explanation of the poor results of the rice cultures on which we first kept books is that they were all on land infested with cogon. There is reason to believe that besides disputing with rice for a place in the sun and ground, cogon excretes substances or leaves them in the soil which are deleterious to rice,[2] as various grasses are known to do to other crops. However, the Lanao Moros succeed with rice on old cogon land.

No amount of cultivation practicable in the Philippines will really free land of cogon, once it is well infested, so long as it is exposed to the light; but it does not endure shade. Mr. José Zamora, in a personal communication, has told me of raising upland rice with almost no weeding by preceding it by a crop of maize, very thoroughly tilled for the purpose of freeing it from weeds. And Francisco [3] found that with cowpeas between the maize and rice the yield was about 500 kilos (said to be hulled rice) greater than when rice followed the maize directly. As the best of a considerable number of rotations tested, both for rice and for the sum of all crops, Francisco recommends a legume, maize, a legume, rice, and then repeat.

[1] Ramos, F., "Distribution of Income from Upland and Lowland Rice," *Phil. Agriculturist*, 10. (1922), 443.

[2] Villegas, V., "Experiments on Rice in Water Cultures," *Phil. Agric. and Forester*, 2. (1912), 86.

[3] Francisco, G., "A Series of Crop Rotations," *Phil. Agric. and Forester*, 6. (1917), 62.

Upland may be compared with the other rice cultural systems before lowland rice is taken up in detail. As compared with caingin rice-growing, the cultivation of upland rice has an important place in the established agriculture of populous districts; while caingin-making is the characteristic practice of the "wild" people, and is only possible where the population is too sparse to keep its land in use, and beyond the reach of any Government able to preserve the forests and limit the wild grass areas. And no people properly equipped to cultivate the land would be willing to clear off forest for every third or fourth crop for the sake of having one of the crops very productive.

As compared with lowland (transplanted) rice, the average production of upland (direct planting) is less. While single varieties of upland rice are locally highly prized, it is also true that the average quality of lowland rice is better. And lowland rice is a surer crop. In spite of all these comparative disadvantages, upland rice holds its own as an important crop. The chief reasons are the cheapness and abundance of suitable land. The grading and diking of paddy land may double the cost and price, or may treble them. Much upland rice land is owned and farmed by people too poor to afford paddy land. There is also much upland rice on land so uneven that its conversion to paddy would be exceedingly expensive and at present prices altogether unprofitable—although none of it is nearly as precipitous as the Igorots have terraced and irrigated. Most important, upland rice culture has a place in general agriculture, land being used, now for rice, now for some other crop; while the construction of dikes dedicates the land to rice, and unfits it for most other uses. Upland rice is very generally the first crop grown on land intended eventually for coco-nuts, or some other permanent crop, and continues to be raised as a catch-crop while permanent tree plantings do not yet occupy the most of the ground.

Upland rice will remain a crop of some importance

at least as long as the cultivated area of the Islands continues to expand. And the use of productive varieties and the practice of rotation will probably make it remunerative enough to hold its place indefinitely.

Camus's third system of culture, called *sabog* or broadcasting method, is intermediate in character between upland and lowland. The land is diked and graded and prepared as for transplanting, and the seed is then broadcasted on the field. This practice is confined to a rather limited territory, and is used only for a second crop where the supply of water for irrigation is or may be inadequate. The crops obtained by this method are smaller than by transplanting. Its advantages are some saving of time, saving the labour of transplanting, and the possibility of maturing a crop with less water; rice grown directly in its place can get along with less water than transplanted rice. The varieties generally used for this kind of planting are said by Camus to be *Binicol*, *Dinagat I.*, *Pinursigue*, *Sinadyaya*, and *Mangasa*. The first three, as known to me, are typically upland varieties but can thrive also as paddy rice. All are early varieties compared with Philippine rice in general, maturing in one hundred and twenty-five days, more or less, from planting. Seed is sown at the rate of 35 gantas per hectare, more than one-third in excess of the requirement for transplanting.

This system is not in very wide use. With improvement in irrigation systems it may disappear, for the saving of expense in seed-beds and transplanting is likely to be more than offset by the smaller yield. On the other hand its use may become more general, for scarcity of labour to transplant the first crop in the limited available time is in some places the factor limiting production, and is becoming more acute. A practical suggestion by Mr. Silayan is that where the labour available for transplanting limits the production, one crop out of two or three on each field be transplanted and the others broadcasted; the available labour could thus produce more rice.

Before taking up lowland rice, it may be noted that there are local, special practices not conforming exactly to any of the four types of culture. In some places—among them, Olongapo—irrigation is accomplished as in Carolina, by the rise of the tide; but, in the absence of a real river to provide fresh water in this way, decidedly brackish water is used, and a particular local variety, able to endure more salt than ordinary rice, is planted. A modification of the upland method is practised in places on the flat shore of Laguna de Bay, where the lake keeps up the water table in the soil, so that there is sufficient ground water, whatever the season.

The rice-growing of the Lanao Moros stands between the caingin and secano methods, being like the caingin in that the land is periodically abandoned, but different in that it is very really cultivated. It has long been known that the Moros raised upland rice successfully on cogon land; and Mr. Silayan, formerly Deputy Governor in charge of agriculture in that province, has given me the details. The first step is to cut the cogon, in the latter part of the rainy season, and let it decay on the ground. After two or three months it is burned over if necessary, but ploughed without burning if this can be done. The ground is well harrowed, and then gone over by hand, the underground stems of the cogon being picked out and burned. If necessary, in order to clean the ground thoroughly, this whole operation is gone over a second, and even a third time. The rice is then planted in a plough furrow, each passage of the plough covering the rice in the preceding furrow. When the land is abandoned, it returns to cogon, and is reclaimed when wanted. The secret of success is thorough and repeated cultivation, and the picking out of all cogon. Beyond this, the Moros have a variety, *gariyasa*, especially suited to cogon land, raised for this reason, though of poor quality.

The fourth and most important method of culture is known in English as lowland rice, paddy rice, and the Chinese method. While usual on low lands, rice is

carried by this method to greater altitudes than it reaches by any other, even the caingin. The word paddy, *padi* in Malay, *palay* in many parts of the Philippines, means simply rice, the plant in the field and the grain in the rough, regardless of the method of culture. Filipinos refer to this method as *tanim*, the same root meaning harvest or crop in general, just as the Chinese word for agriculture also refers specifically to the growing of rice in this manner. To distinguish between methods, the Tagalog call this method *tubigan*, from the root meaning water. The one characteristic of this method is the transplanting. It is the typical Oriental method of growing rice, incomparably the most extensively used, and that by which all Oriental rice which is an article of commerce is produced.

The rice to be transplanted is grown first in seed-beds. In the northern rice country of the Philippines, which happens also to be the land of bearded rice, the seed-beds are prepared dry. The ground is thoroughly ploughed and harrowed, and the seed thickly scattered on long, narrow strips. The ground is then harrowed or dragged again. The bed is never puddled or flooded. The seedlings are pulled up in bunches, after they become strong enough to endure such treatment. In the absence of statistics, it may be presumed that this kind of seed-bed produces better stooling than any other. It may or may not involve more damage to the roots, in pulling. The development of root systems in the various kinds of seed-beds, and the respective benefits and injuries done by the "root pruning" when the seedlings are pulled up, have never been studied.

The general practice elsewhere in the Philippines, and elsewhere in the East, is to make the seed-bed on puddled ground. The preparation of this ground is most thorough, consisting of wet ploughing twice or oftener, harrowing as many times as may be required, and smoothing. What is called harrowing, for want of a really applicable English word, is performed with a comb-like implement, called *suyod* in Tagalog (a Philip-

pine dialect), dragged through the mud, until the latter is reduced to a clean and uniform gruel-like consistency. The seed-bed is usually close to the house, for the sake of convenient care. It must not be shaded, and must be safe from animals. Relatively light soil is desirable. A good start before transplanting is absolutely necessary, so that the seedlings may recover from transplanting, and do well afterward. This is generally understood, and accounts for the care given to the seed-beds. Manuring these beds is not unusual, but manuring the fields is almost unknown in the Philippine lowlands.

The area of the bed is about one twenty-fifth of that of the field to be planted, varying somewhat with variety, soil, and season. At this rate, for one hectare of land the seed-bed is four hundred square metres. On this, twenty to twenty-five gantas[1] of seed are sown. Camus explains this by the following calculation:

> One cavan of palay contains about 2,000,000 grains, and not over 75 per cent will germinate if it is unselected seed. There are approximately 250,000 hills 20 centimetres apart in one hectare, so that in planting seed of ordinary-sized grains two to four seedlings to the hill, about 20 gantas will be required to plant a hectare. When using selected seed or a late maturing variety less than 20 gantas are needed.

Before planting, the bed is drained off, and may be allowed to become partly dry it the soil is light. The seed is soaked for a day or more, and then mostly germinated in the air, in the shade, before planting. Thereafter the seed-bed is kept uniformly moist, but not allowed to flood; too much water would make the seedlings too soft and spindling to endure transplanting. Seedlings remain in the seed-bed for a month or

[1] The *ganta* (*gantang* in Malay), one-twenty-fifth of a *cavan*, is a measure of volume, supposed to be equal to three litres. One ganta is defined as weighing 1·744 kilogrammes, or 3·843 lb., but this varies. The cavan is the usual "sack." It is also the area planted with one cavan of seed, usually not quite one hectare (2·47 acres), corresponding roughly to the Dutch "bouw." Twenty gantas of seed per hectare, using the weight just given, equals 31·1 lb. per acre. The consistent use of the cavan as a unit measures the yield in terms of the seed; a twenty-cavan crop is a twentyfold crop.

more, properly depending upon the variety. The stage reached determines transplanting time, the earliest varieties being ready within thirty days of reasonably good weather, the latest varieties requiring forty days. When they are ready, assuming that the field is so, the ground of the bed is completely soaked unless exceptionally light, and the seedlings are pulled up and tied in bundles as large as can conveniently be held in the hand. The tops are then cut off. This limits the loss of water from the leaves while the roots are re-establishing themselves. How much pruning is needed depends upon damage to roots, condition of ground, and weather; one-third of the height is usually quite enough to remove. Recovery from transplanting should require very few days.

A third method of handling the seed-bed, locally used where I have lived, coming into more general use, and strongly favoured by Camus for use whenever early maturity is wanted, is called *dapog*. The seed-bed is placed where water is at hand, and puddled and smoothed in the usual way. Banana leaves are then split down the middle of the midrib, the narrowed ends cut off and placed edge to edge, and pressed in so that a very little mud oozes over them. Holes and torn places in the leaves, and places where they do not quite meet, are covered with pieces of leaf. To be sure that there can be no open holes left, the beds may be made more than one leaf thick. The beds thus formed are a yard or a metre wide, and indefinitely long. At the ends they are closed by leaves laid crosswise with the edge inward, so that each whole bed is surrounded by a raised border, made by the midribs. As a matter of convenience, two or more beds are made side by side. A cavan of seed will plant two such beds about fifty feet long, which is accordingly a usual length. The beds are then covered with a layer of rice hulls or finely cut straw about an inch thick, which is wet with muddy water.

The seed is soaked and germinated in the air, in

the usual manner, and scattered thickly over the bed. Constant care is required to keep it wet, at first by sprinkling, and then, as the roots grow and begin to make a mat, by flowing water. If the weather is hot and clear, the bed needs to be shaded, which is done with banana leaves or bamboo branches placed on frames. Transplanting is performed within two weeks after germination. Only early varieties are handled in this manner; the saving of time in the seed-bed, over that by the usual method, is therefore about one-half.

Like any other seedling, that of rice grows at first by the use of the food stored in the seed. This suffices for the growth of roots to hold it in place and take water and food from the soil, and leaves to make carbohydrate food in the air. At any time before the food in the seed is approximately exhausted, the seedling might be transplanted quickly without much injury; but this is impracticable because of its small size and delicate texture. There follows a period during which the food-store left in the seed is insufficient to re-establish the roots, and the seedling has not yet developed much strength by its own activity, when transplanting with any practicable degree of care would be fatal to all or most of the seedlings. Presently, the roots grow tougher, so that they can be pulled out without being broken off too short; and some of them contract and pull the seed below the surface of the ground. The little stem thickens, accumulates some food, and, without growing much in length, begins to branch. Too much water does not quite prevent, but does interfere with, this branching, which is the first step toward stooling; it tends to promote growth in length, at the expense of storing food and branching. It is for this reason that the ordinary seed-beds are not kept saturated. There comes presently another stage in which the strength of the roots and the food in the compact stem structure make transplanting practicable. If it be delayed longer there will be a relatively great loss of roots in pulling, more of the leaves will have to be cut away to prevent

death from loss of water, and recovery will be much slower. As already noted, this best time for transplanting is thirty to forty days after germination, where the seedlings grow just so thickly that they have room to develop normally up to that time.

The essential featüre of the dapog method is that the roots are kept from growing into the soil, and therefore are subject to relatively little damage in transplanting. This makes it possible to transplant with comparative safety, without waiting until the plant would be strong enough to endure it, if done in the usual manner. This method requires, as well as makes possible, early transplanting; if the dapog bed were left the usual month the seedlings would be weaker than in mud, and the roots grown together until they could not be separated. In spite of the relative freedom from mechanical injury in transplanting, the mortality is greater than by the usual method, more seedlings are placed in each hill, and the amount of seed sown for each unit of field area is about twice as great.

For transplanting, the banana leaves are lifted up and torn into strips a few inches wide, each bearing a mat of seedlings. The strips are taken to the fields, with or without rolling up, and there made into smaller sections, which are scattered over the mud at proper distances, just as are the tied bundles of seedlings in the general practice.

Paddy land is made in the first place by terracing on land with appreciable slope and diking. The only instrument in common use for finding grades and levels is the water. This permits very perfect levelling inside the dikes, and the levelling is facilitated by the local method of final cultivation, giving the soil the consistency of soft mud, and by the aptitude of the carabao to work in mud. The use of water to determine the position of the dikes results in small and irregular checks. The dikes are permanent. They are carefully made, kept in order with reasonable care, and not permitted to become wide; this is important, both for the sake of

any cleanness of cultivation, and, in view of the smallness of the single paddies, for the economy of area. They are a serious impediment to the cultivation of any field as a whole, in spite of the facts that the carabao is facile at stepping over obstacles and that the ploughs are very light. When the cultivation is of one paddy at a time—the usual practice—their smallness wastes a great deal of time in turning. Camus calculates that in paddies 10 by 100 metres, one-eighth of the time is thus lost; and that in paddies 16 by 33 metres, the loss is three-eighths. Even this may be above the mean size in the Islands, although less than one-seventh of an acre.

The preparation of the land for the seedlings to be transplanted is far less thorough in general Philippine practice than would produce the best crops. It is less thorough than seems to be usual in Burma and Cochin-China, much less thorough than the usual practice in Java, China, and Japan. But before one criticises any established practice, it is worth while to remember that it is very unlikely to have become established without some fairly adequate justification which may escape the critic, and may not be understood even by those who follow the practice. The Filipino ascribes his imperfect cultivation primarily to the shortage of draught animals, and feels that, if supplied equally well with the Indo-Chinese, the Philippines would raise big enough crops to export instead of importing a part of their staple food. This is probably true, but it would be accomplished immediately by increasing the area rather than by better crops from the area now cultivated.

The more essential correlation of Philippine rice cultural practices is with density of population and the utility of effort as applied to other crops. As these vary from place to place in the Philippines, so does the preparation of the rice fields. Where the population is relatively dense in real rice country, the tendency is to give the ground better care. The same is true in some places where there is but little rice land, and the effort is to raise as large a part as possible of what is locally needed. But

where other crops repay labour better, and rice is grown incidentally, even as a matter of economic compulsion, cultivation is likely to be less thorough. And still more, where good land is abundant and cheap, because the population is sparse, given effort produces more rice if applied to a larger area than if devoted to securing the largest yields from a small area. Nueva Ecija, for example, has recently moved into first place among rice-producing provinces by a rapid influx of settlers. The yield per acre is high because the land is new. It is certainly good business here to farm areas larger than the average in any other province, rather than to farm intensively; and in appraising the local practice, it is fairer to consider yield per capita than yield per hectare. We know that Spain produces more rice per acre than California, but do not conclude that Spanish methods should therefore be adopted in California. Rice is grown for profit, not reputation.

The preparation of the paddies for planting consists in the Philippines of ploughing and harrowing by means of stock, usually carabao (water buffaloes). Most such land is too hard to be ploughed dry, but it is best ploughed in as dry a state as may be feasible. It is then harrowed with a bought harrow or with a home-made one of bamboo, which may do very good service more slowly. It is then allowed to stand for a time. If given what is regarded as good cultivation, it is then ploughed again. At the best it is again left while any seed that will may germinate, and then harrowed. The final step is puddling, more or less perfectly, with bamboo harrow, or, better, the *suyod*. If the work is well done it is then perfectly weed-free and permits very easy insertion of the seedlings.

Women and children do most of the transplanting, and become remarkably proficient in it. They walk backward in the mud, with a bundle of seedlings in the left hand, from which they grab a pinch with the right and jab it into place, and so on—faster than one can read the account; and the pinches of seedlings are left

PREPARING THE PADDY, WITH SUYOD.

Photo by the Philippine Bureau of Agriculture.

To face page 232.

in fairly regular rows in both directions. The usual number of seedlings transplanted together is three to five. The proper number depends upon the probable mortality, their vigour of growth, and the varietal propensity to stool; a smaller number than are planted would usually be better. The proper distance between clumps depends upon propensity to stool and ultimate height, which is probably correlated somewhat with age at maturity. Too close planting is usual. Working with a variety customarily planted with three to five seedlings in clumps at most six inches apart, we found at the College of Agriculture that the spacing giving the greatest yield per hectare was eight inches between clumps of one or two seedlings.

Eight or more women, depending upon their expertness and the spacing, are required to plant one hectare in a day—say three days' work to the acre. This work is always done by considerable parties of workers, and must be so done to provide uniformity of the field. It is rarely paid for in cash; if it is, the wages are usually less than prevail for men. Typically, it is done by neighbourhood co-operation, the families going from field to field, the meal at work being provided by the owner of the field they happen to be working on. Between this and direct payment there are countless details of arrangements as the old system of community enterprise dies out, and in adaptation to size of field and family. If payment is a fixed wage per day, whether in cash or not, the slowest workers almost inevitably tend to set the pace. It used to be common to provide music in the field, and this speeded the work up materially. Rarely this is still done, but the value of the stimulant depends upon the disposition of the workers to be stimulated, which, in turn, on any considerable scale, depends upon the really co-operative nature of the work.

However paid for, transplanting contributes to the real cost of the crop in proportion to the labour it entails. Camus even suggests that the practice may cease in the Philippines, in the absence of a machine to perform the

work, as wages become too high to permit it. In reality no such outcome is in sight. One reason is that food prices and wages have a general tendency to vary together, it being money which varies most in value. Another is that established industries maintain themselves, and no other Oriental industry is nearly so firmly fixed as this. Lowland rice production represents by far the greatest investment of capital among Philippine industries, and this will not be readily or quickly sacrificed. But the chief reason is that the transplanting, with the correlated practices, pays. The estimates of the Bureau of Agriculture indicate that the production cost of a cavan of rice is less by the lowland than by the upland method, and would still be less if, all other costs remaining as they are, transplanting cost three times what it does. Rice must and will be produced, and the rise in wages is no phenomenon peculiar to the Philippines. Higher wages in Japan have not cut down rice production by this method. And I do not know that wages are the essential bar to its use in California.

A large part of what this method of culture costs in transplanting it saves in weeding. Culture in water, here as elsewhere, precludes trouble with the weeds of dry land. And the water weeds, many of them started and killed off before transplanting, start at best far behind the rice, and can by no possibility overtake and overcome it, as they often do in the United States. Some sedges and grasses do usually appear before the rice matures. A little weeding is done, and a little more would probably pay in the course of time, if not at once. In Java and Japan and Southern China, the paddies are kept clean, clean in a sense that calls for another word to describe it. I have never elsewhere seen any crop in the absolutely undisputed possession of the ground that paddy rice is given in those countries.

Provision of water, as a rule, costs very little. Typically, rather than usually, there are engineering works to divert the water of a stream and bring it to the paddies. Some of these works constructed long ago are very fine ;

TRANSPLANTING RICE.

Photo by the Philippine Bureau of Agriculture.

NEWLY TRANSPLANTED PADDY.

Photo by the Philippine Bureau of Agriculture.

To face page 224

as a rule they were built by the church to irrigate church lands. The area in the Islands under what the Bureau of Public Works regarded as irrigation was 50,587 hectares in 1912, and a survey in 1920 showed 559,000 hectares which could be irrigated easily. But the area in rice was reported as 1,078,891 hectares in 1912, and 1,484,895 hectares in 1920, and three-fourths is estimated to be lowland. Aside from gravity diversion, there is some mechanical lifting of water from streams, by pumps and otherwise. There is a great deal of paddy rice planted in complete and direct dependence upon the rains for water, the dikes storing it on the land. And some is irrigated with the help of the rain, by water from temporary watercourses.

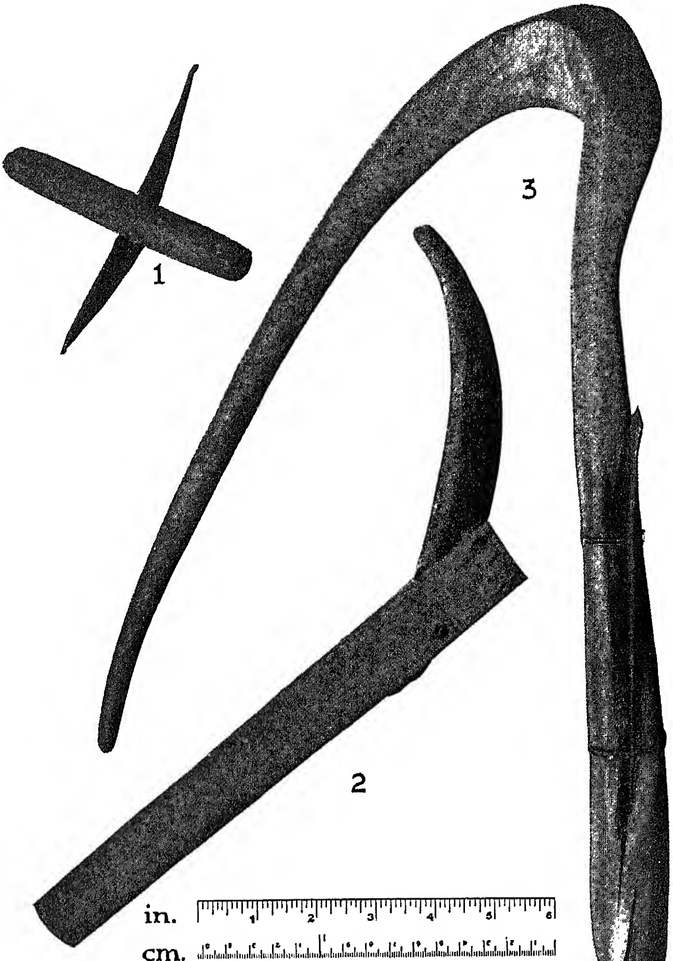
The Bureau of Agriculture estimates the total cost of all work, including weeding and irrigation, between transplanting and harvest, at two pesos per hectare, or forty cents of American money an acre—one day's wage. It has just been shown that weeding costs almost nothing. And the rain is free, and most rice is raised during the rainy season. The one day's labour is actually demanded chiefly for the care of the dikes. Artificial irrigation, of course, costs more than this figure indicates, and costs more for a dry or partly dry season than for a rainy season crop, whether or not this appears in the current cash outlay. The Bureau of Public Works has taken due account of the fact that Philippine rice demands cheap water, in planning irrigation works. But it must not be concluded, because rice water costs an average of hardly one day's wage, that rice cannot pay for real irrigation. It can do this by larger crops, more uniformly good crops, still more by more certain crops, and by making two crops a year safe where only one can be grown without it.

As to the practice of irrigation, no water is applied to the paddies for some days after transplanting. Thereafter, it may be held continuously, or the field may be deliberately unwatered once. The water is finally drained off as the rice goes from the "milk" to the

"dough." Where dependence is upon the rain, nature may take precedence of the grower in fixing the depth of the water, and make it unsafe deliberately to decrease the depth. In most parts of the Philippines the dikes are low, and water is never held more than four to six inches deep. But in Pangasinan, formerly steadily the foremost rice province, where tall, bearded varieties predominate, deeper water is the rule. Tests at the College of Agriculture with water held at various depths showed the best yield where the ground was steadily kept thoroughly wet, without measurable standing water, and a steadily decreasing yield with increased depth of water. This might not have been found true of all or most varieties. But the warmer nights and high humidity amply explain the propriety of keeping less water on rice here than in California.

The total water required to mature any crop except the very late varieties is fixed by Camus at forty-four inches, depending, of course, upon the soil; this would not suffice for a crop a month earlier, on the tightest ground in California. As a rule, having an abundance, the Filipino wastes water. When much rain falls on the paddy, there is nothing to do but let it go freely. But with irrigation water there is another object, which may be more important than economy of water, for holding it; the water of streams always contains some, and may contain a very considerable amount of mineral material valuable to the plants, which can be saved for them only by evaporating it on the ground.

Harvesting is done as early and as quickly as possible. It is always by hand. The knives used are most various, but can be reduced to three general classes, all serrated, called in Tagalog *yatab*, *caret*, and *lingcao*. The figures give a better idea of these than can be done by words. The first is a knife six inches long or less, fastened crosswise in a short stick. It is most used for upland rice, bearded rice, and any rice especially prone to shatter. That it is the original harvesting implement is suggested by its having also



TOOLS USED IN HARVESTING RICE.

1 Yatab 2, Caret; 3, Lingcao.

(From Camus: "Rice in the Philippines.")

To face page 236.

HARVESTING RICE.

Photo by the Philippine Bureau of Agriculture.

To face page 237.

he name *pangani*—the thing that habitually harvests. Vith it the heads are removed singly or a very few at time. In upland rice, raised for local use, in Laguna nd Batangas, the heads only are removed, put into askets, and threshed by tramping without any curing. n harvesting Pangasinan bearded rice, which goes into ommerce on a large scale, the stem is cut far enough elow the panicle to permit tying into bundles, which re dried briefly, and may then be sold; but this rice s always cured in the stack before threshing. All rice n Leyte is cut in this manner. This is the typical avanese method of harvest.

The caret is a small sickle or grass-hook. In various orms, and with various names, it is used throughout he Islands, but is a less specialized tool than either of he others.

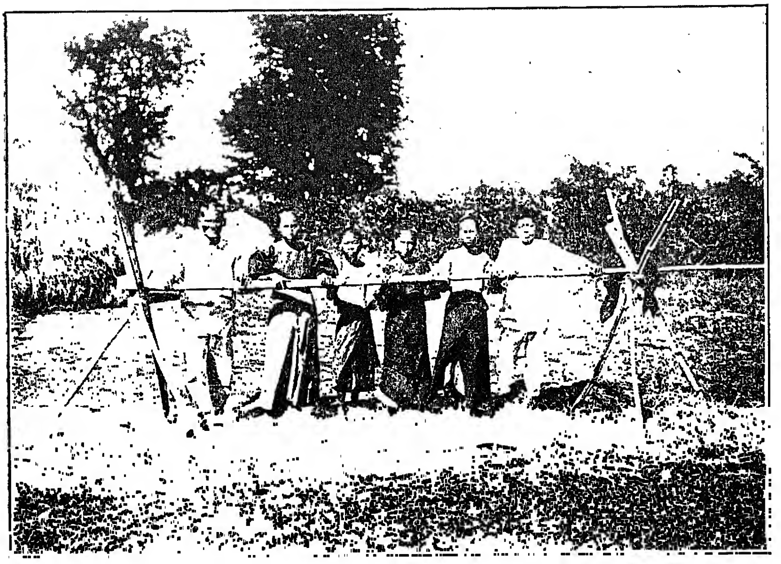
The lingcao has a knife like that of the caret, fastened nto the back of a peculiar piece of wood in the form of hook. This is the chief harvest tool in the beardless ice of the leading rice-growing provinces of Luzon. The hook draws together a bunch of rice, which is held ear the top with the left hand, while the right turns he tool over and cuts the bunch off, with perhaps a oot of straw. In most places these bundles are tied as they are cut, and left to cure, at least that day, on the ground where cut. They are so uniform in size that they serve as a unit of measure. Later, they are usually shocked or stacked together on the dikes. Finally, they are assembled at the threshing place or floor, and very perfectly stacked.

The harvest is paid for in all sorts of ways. It may be paid for in cash, in which case the price is likely to be rather high, as local wages go; or it may be a co-operative job; or it may be anything between these. Probably the commonest payment is with a share, of one-tenth or more. I have known the share to be one-twelfth, and Camus says it may reach one-half. It depends naturally upon the demand for labour, the price of rice, and the quality of the crop. Where curing in

the stack does not intervene, one share is likely to be paid for cutting and threshing together, and this may not exceed one-eighth. As to the value of the payment, the share is usually worth more than the going cash wage.

In the larger part of the Islands, threshing is still done by the methods the ages have sanctioned, but in the chief rice-producing provinces threshing machines have become common. The price of threshing with machines may be fixed in cash, or may be a share, commonly 8 to 10 per cent. This is a high enough share, considering that there are no bundle wagons for the threshers to operate, there is very much less straw to thresh than where binders are used, and the grain is loose and always well cured before threshing. On the other hand, the machines, engine as well as thresher, are far from the factory and expensive, depreciation is rather rapid, and fuel is costly. The lack of more general use of threshers is not because they are unknown, but chiefly because they are expensive, and not practically useful where rice is scattered and roads very poor. Also, there is a general preference for rice threshed by the older methods for home consumption, due apparently to poor adjustment of the machines.

The more primitive methods are treading out by foot, rolling with big, toothed wooden rollers, pulling over a sort of comb, flailing, and, far most common, treading out by stock. The last is sometimes performed on mats, but usually on hard earthen floors, prepared for the purpose on high, dry ground. The treading out is usually done at night, and by parties of workers and animals, commonly carabao, less often horses or cattle. The stock is driven around and around for hours, the standard of efficiency being three cavanes an hour per carabao. The final cleaning of the heads is done by the labourers. At best, no threshing machine can remove and save the grain as completely as the older methods do; but the other objections to the work of machines—too much broken grain and contamination by weed seed



FILIPINOS THRESHING RICE WITH THEIR FEET.

Photo by the Philippine Bureau of Science.

CARABAOS THRESHING RICE BY TRAMPING ON IT.

Photo by the Philippine Bureau of Science.

To face page 238.

—are due to poor handling. One-tenth to one-sixth is the normal share paid for tramping out.

The most efficient known technique of threshing by foot is that practised in Leyte. The rice is beardless, harvested with the *yatab* as in Pangasinan, and, except for immediate local use, is cured. A platform, eight or ten feet high, with bamboo floor with cracks between the slats, is then erected. A rope is stretched above the platform; to this the workers hold with their hands, while they work the rice with their feet. The grain falls through the cracks, is winnowed by the wind, and collects, clean, on a mat on the ground. An efficient worker separates as much as fifty cavanes a day in this way. The remarkable feature of this method is the removal of the grain as fast as it is separated from the straw, so that the worker sees constantly what remains to be separated.

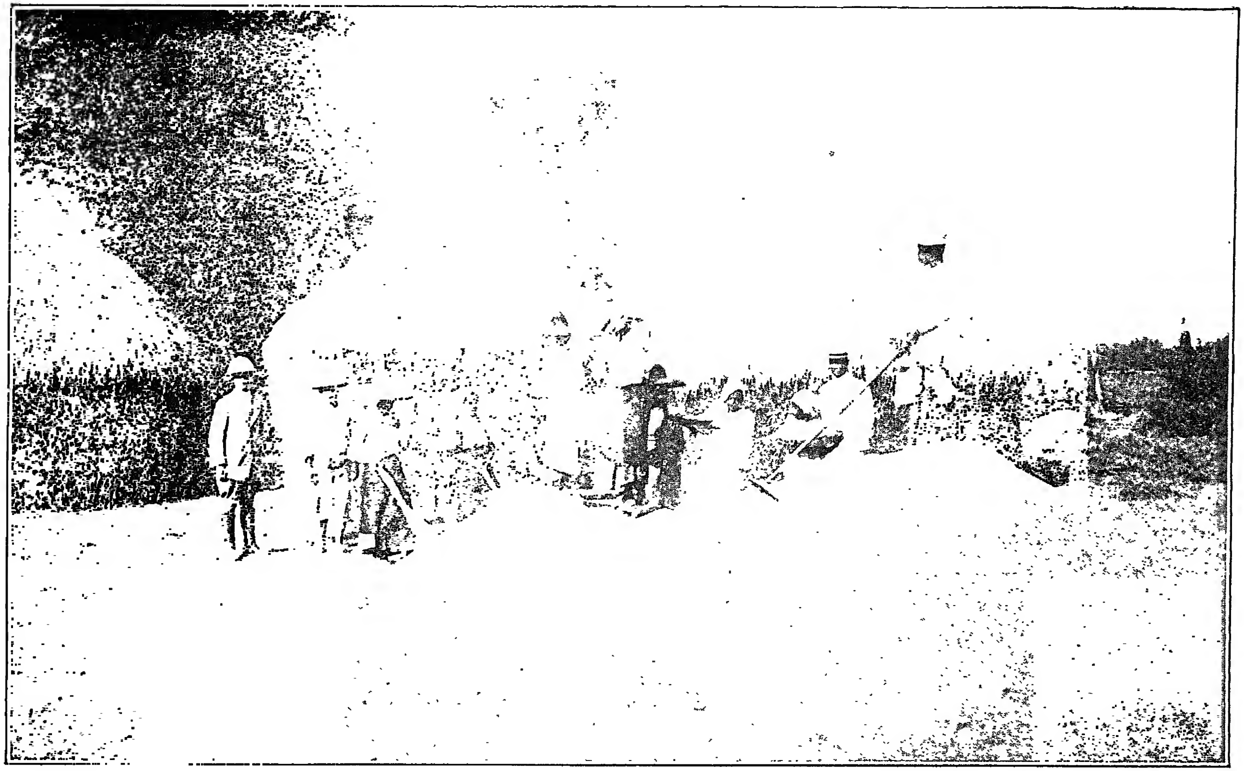
There are in the Philippines very few rice mills at all comparable to those in the United States or, nearer, at Cholon, in Cochin-China. Scattered over all country where any appreciable amount of rice is produced are small mills, run by engines of six or eight horse-power or driven by water power. These operate by grinding between stones or metal discs, after which, in the common, compact imported machines, the polishing follows so directly that hulls, bran, and polish come out mixed together from one spout, and the finished rice from another. In the locally-contrived mills, the chaff (mostly hulls) is separated by hand or by a fanning device after grinding, and finishing is done by power-driven pestles. So far as enough is grown locally, such mills supply the local markets, and, if there is a surplus, ship it. The milling charge may be twenty to fifty centavos a cavan in cash; or milling may be done for the by-products; or one-half (or a little more) of the weight of the rough rice may be returned to the grower in finished rice.

Everywhere in the Islands, more or less rice is still cleaned by hand at home. In this process, it is first

ground over a fixed stone and under a rotating one, through which the rice feeds down; this is called a *guilingan*. The separation of chaff is finished by winnowing, in large, flat baskets called *bilao*. The "brown" rice is then put into a wooden mortar and pounded with a wooden pestle. The expertness of the women, and even the little girls, in winnowing, and particularly in handling the great pestles, working two together into one mortar, used to be one of the sights of Philippine country life most impressive to the stranger. Finally, the fine chaff and powder are removed by winnowing again, and the rice is very thoroughly washed before cooking.

Lowland rice-growing is a very uniform procedure wherever there are "Filipinos" in the stricter sense of the word. The same essential uniformity prevails, as a generality, throughout the vast hot-bed of humanity filling the triangle between India, Japan, and the Islands east of Java, wherever in this area there is really well-established agriculture. Where the practice is most intensive, pressure of population is quite sure to be the reason.

Igorot Rice.—The terrace cultures of the mountain people of Northern Luzon, often collectively called Igorots, are an example. These people have exceedingly close social horizons. Each group of a very few settlements has its peculiar cultural marks, developed by dwelling through ages in the single spots, without any idea of the world except for a few miles about, and very often in constant hostility toward the nearest neighbouring communities. Measured by the number to the square mile, their country is sparsely inhabited. But it is so ruggedly mountainous that, measured by the land which the hardest work can make into paddy, the population is very dense in spots. The most striking activity common to all of these people, and the one thing that raises them above the grade of savages (except, of course, as very recently they have come under the influence of the Government), is their rice culture.



FILIPINOS CLEANING RICE.

Photo by the Philippine Bureau of Agriculture.

To face page 240.

They have cut terraces in the mountain sides, wherever these could be watered, near enough to their settlements to be reached and watched with safety. In making these, the soil is carefully removed and saved. The terrace is then made, with almost vertical walls of stone, laid without mortar or mud, and a bed of stone, on which the soil is replaced. Other soil is carried in if needed. There are terraced hill-sides which are not stony, but stone is the rule. The width depends of course upon the slope, but in the rare places where they could be more than, say, 50 feet wide, it is easier to make lower walls; these may then be only a foot high. Commonly they are several to many feet high. I have seen them up to 30 feet or more, and they reach 75 feet. In general, the higher the wall the narrower the terrace. Such land-making represents a really great investment, and is the capital saved up by the labour of unnumbered generations. I quote Jenks[1] as to the effect:—

> A single area consisting of several thousand acres of mountain-side is frequently devoted to sementeras, and I have yet to behold a more beautiful view of cultivated land than such an area of Igorot rice terraces. Winding in and out, following every projection, dipping into every pocket of the mountain, the walls ramble along like running things alive. Like giant stairways, the terraces lead up and down the mountain side. . . .

As some few terraces could be built easily, so are some easily irrigated by the diversion of a convenient stream. Whatever the difficulty, the water is used. In one place near Bontoc, the water is diverted by a dam, which has to be rebuilt every year, and carried more than five hundred feet across a vertical rock cliff in a flume made by gouging out pine logs and fastening them end to end, above flood-level. Ownership of the paddy is personal, but the ditch making and tending are co-operative, and the water is served to the several users in turn as it should be needed.

[1] Jenks, A. E., *The Bontok Igorot*, Manila, 1903.

Absolutely nothing which could enrich the ground is wasted. The domestic animal is the pig, kept in a small sunken pit. Into this everything goes, with dry grass, etc., to hold all excreta against waste and decay. When the land is to be worked, these pits are cleaned, and the contents carried to the fields in baskets by the men and perfectly worked in. All work is by hand.

This is indeed strenuous agriculture. And the heritage of terraces—land valued at the equivalent of two or three thousand days' work an acre—depreciates to almost nothing when roads are opened and the economic isolation of the community ends.

Terracing of this type has been practised by local mountain peoples in a considerable number of places, all, within historic times, isolated from each other. Nowhere else has it reached quite the perfection of development, in extravagance of work and completeness of use of water, that it has among the Igorots. The nearest approach is probably in Lombok and Yunnan.

MEANS OF IMPROVEMENT

To conclude the discussion of Philippine rice, before taking up other Oriental countries for brief treatment the means of improvement will now be considered.

Better Seed.—Clearly first among these, for both upland and lowland rice, to increase crops and make them more profitable in the full measure of the increase is the use of better seed. Referring to Chapter IV. for the consideration of this subject in general, facts and considerations with particular reference to the Philippines are in order here. About 3500 varietal names are reported in the islands. 1282 supposed varieties had been tested by the Bureau of Agriculture at the end of 1919, and 991 of these were found to be distinguishable; whence it may be presumed that two or three thousand are grown. And there is probably not one of these country varieties that is not itself a mixture.

"IGOROT" RICE TERRACES.

Photo by the Philippine Bureau of Science.

To face page 242.

Obviously, there are no such ranges of conditions and demands as would call for any considerable fraction of this number of varieties.

If no varieties were inferior in quality or productiveness, it would still be best that most of them disappear from cultivation, to simplify the problems of growing, milling, marketing, and using. The task of undertaking improvement of cultural methods by giving out or by following specific recommendations is baffling to the student or official and disheartening to the farmer, while there are in cultivation almost countless more or less ill-defined varieties, to one or some of which the advice applies, at least under some conditions. The farmer may know another rice by the name the experimenter uses, and may happen to know that rice by a different name. So that not only is it impracticable to apply to rice in general the detailed conclusions from work done with single kinds—which is necessarily so, and for which there is no help,—but there are dangers even in its general application to rice having locally the same varietal name, unless the identity is more clearly established. And it is neither possible nor worth while to make any very thorough study of thousands of varieties. The first condition, then, for any general and prospectively long programme of improvement is the detection and elimination of a great number of really superfluous varieties.

The varieties are in fact very unequal in productiveness, leaving out of account rating of quality, which is much harder to grade. Jacobson[1] reported that of varieties tested by the Bureau of Agriculture, 43·38 per cent produced over two metric tons of paddy rice to the hectare, under experiment station conditions (which include no use of fertilizers, but do include sufficient water); 39 per cent yielded between one and two tons; and 17·6 per cent, less than one ton. Divide by two, and these figures are approximately short tons per acre.

[1] Jacobson, H. O., "The Causes of Low Yields of Rice in the Philippines," *Phil. Agric. Rev.* 7. (1915), 262.

In the absence of very exceptional quality, every variety yielding less than two tons should be eliminated. If these figures be construed as general, and it be concluded that only 43 per cent of all varieties are even reasonably productive, it does not of course follow that only this percentage of the rice grown belongs to such varieties; for the farmers naturally exercise a preference for varieties expected to produce well. But it certainly is true that the complete elimination of varieties proved to be inferior would effect an immediate increase in the yield and profit of Philippine rice. Nor is there any reason to keep 43 per cent of existing varieties, even on the basis of yield alone.

There ought likewise to be a general elimination of exceptionally late varieties. It appears from Jacobson's figures that 34·9 per cent of tested varieties require more than 180 days to mature. There is no evidence that beyond this limit long life is correlated with high yield. But it does involve expense and prolonged risk from exposure to various dangers, and keeps the land wet and occupied, where there is no risk of want of water; and where the irrigation system is wanting or imperfect the risk of loss is very great. Out of the 1282 varieties or supposed varieties tested, the Bureau of Agriculture turned thumbs down on all except 44; only one of which, in the experiment station records, yields less than 2300 kilos per hectare, and only two of which require more than 180 days.

Along with the selection of varieties, and with equal promise of profit, there goes on selection of strains within the varieties. It is generally understood that under any set of uniform and tolerable conditions, individual plants of a variety will produce unequally; and yet, almost any grower of any crop is surprised if shown how great is the difference between his plants. This theme, including its Philippine aspects, has been developed in Chapter IV.

There is unquestionably an opportunity for some economy of seed, beyond what is actually practised.

Jacobson[1] says flatly that 750,000 cavanes of seed, beyond real needs, which he figures liberally, are used for each Philippine crop. Beyond the use of seed in excess of needs by current practice, improvement of practice in several respects can effect added economy. Wider spacing and fewer plants in the clump are examples. While Jacobson seemed to suggest that 100 sq. cm. (say, 16 square inches) is room enough in general for each plant, technical opinion is generally agreed that wider spacing gives better yields; and his own figure of 34 sq. cm. per culm, as proper space, demands more room than this wherever the average number of culms to the plant exceeds three. The very high yields obtained with pure strains by experiment stations, and the yields higher than usual averages obtained with country varieties when most local practices are imitated, are usually with one or two plants in the hill, instead of the larger number usually planted. Any means of decreasing the mortality of the young plants would also operate directly to decrease the amount of seed required. However, economy of seed must be cautious and judicious. It would be wretched economy to risk any appreciable decrease of crop for the sake of the utmost possible saving of seed.

Irrigation.—The provision of safer and more ample water supplies is a certain means of increasing rice production. A better supply of sure water is the most essential element. It has already been shown that a very large part of the rice depends upon rain for its water supply. There are years when rain supplies ample water at all times, and practically no rice suffers for want of it. 1913 (the fiscal year ending June 30) was such a year, and the average yield of all land in rice was 21·47 cavanes per hectare. 1912 and 1914 were not such years; the average yields were, respectively, 10·77 and 18·26 cavanes. From June through October in 1912 (the calendar year when the crop of the 1913 fiscal

[1] Jacobson, H. O., "Observations on the Influence of Area per Plant on the Yield of Grain in Rice Culture," *Phil. Agric. Rev.* 8. (1915), 252.

year was raised), the rainfall was well distributed. In 1911 (producing the crop for the 1912 statistics) the rainfall was subnormal in May, June, August, September, and, especially, October; and very heavy precipitation in July did more harm than good. It practically never happens that the total rainfall is inadequate. But drought in October may damage or destroy the crop, whatever the season's total, wherever the dependence is upon rainfall alone; and drought in May and June, when work begins in the chief rice provinces, delays the start and increases the later danger. One centimetre a day is commonly regarded as the rainfall necessary to keep rice thrifty, which is of course not the same for all soils. Just how long the period between rains may be, without injury, depends very much upon the soil as well as upon the dikes, the variety and stage of development of the rice, and the intervening weather. Seasons are of course not alike aside from the insufficiency of rainfall; floods, pests, and economic conditions also make crops vary from year to year. But a study of the statistics of production, in connection with the climatic records, seems to justify the belief that the average annual injury done by insufficiency of water runs into the hundreds of thousands of tons, or more by a considerable margin than the annual importation.

There are two possible methods of cutting down this loss. One is by the more general use of the earlier varieties. July, August, and September are quite safe months; the larger the part of the growing season that is passed in this period the safer the crop. The longer the variety remains capable of injury after September, the more hazardous it is to grow it. But no really good Philippine rice will quite finish its growth within the period of real safety. Also, transplanting requires too much time to be done on all fields in a brief period; and if all rice were of the earliest good varieties, it could not possibly be harvested when ready.

Recourse must therefore be had to artificial irrigation to provide the possibility of an earlier start, and

ensure the crop after the rains become uncertain. Naturally this has been done already where it has seemed possible by local means, but only a minor fraction of the rice land has been taken care of. The Insular Government has, practically from its inception, recognized the fact that it was the only agency capable of handling this problem at all adequately. It has long ago collected very full information in foreign countries, has carefully investigated many irrigation schemes, and perfected the engineering plans for their development, has done a very limited amount of construction and helped to accomplish a little more, and has finally made a comprehensive survey of the irrigation possibilities of the archipelago. For the paucity of results in the form of water during two decades there are several reasons, chief of which has been the basic policy or tendency to promote the social (not to say political) interests of the Filipino people, rather than directly their economic advancement. The one administration most attentive to economic matters was most devoted to improved transportation facilities, certainly needed. The income of the Government has usually been very meagre, and its authority to borrow extremely restricted by statute. Bond money is the usual means by which Governments perform great engineering works. And the Philippine Government will have to be enabled to borrow for this purpose if the huge losses due to failure of water are not to continue.

The survey referred to above, finished in 1922, showed 559,000 hectares susceptible to irrigation in the immediate future. This is far less than the area of lowland rice, but the irrigation of this area would help the rice industry of the Islands in several indirect ways, besides ensuring crops on the land actually irrigated. How much land raises or tries to raise two crops of rice a year is not, apparently, definitely known, but it is very considerable. The value of irrigation in ensuring the second crop, and in making a second possible where it is not now attempted, is too obvious to need argument.

Increased Area.—An important factor in the increase in total rice production, and also in yield per hectare, in recent years has been the expansion of rice area. While the available land in some places has long been quite fully used, there were great areas, not in every case remote, awaiting settlement and use. The advance of Nueva Ecija to first place among the provinces is an eloquent demonstration of what is possible in this way. The colonization of Cotabato has so far had no such results; but when its great valley is well used, it will probably become third, instead of forty-fourth, in rice production among the forty-six provinces and districts.

Fertilizers.—Some improvement can be effected easily by the use of fertilizers. Between the extremes of the Igorot, whose practice has been described, and of those Filipinos who burn the stubble on paddies on land irrigated by rain alone, there is a broad middle ground for improved general practice. What manure, ashes, and decayed matter can be put into the paddies cheaply should of course be there.

Rotation of Crops.—The use of other crops, in alternation with rice, when it is possible to raise them with profit, should strengthen the rice industry, aside from its effects on the value of land and on the local money supply, by improving the soil. In some places, notably in Pangasinan, the mongo is planted immediately after the rice harvest without any cultivation. Being a legume, the mongo enriches the soil in nitrogen in particular, and is regarded as improving it for rice. But the alternative crop is surest to improve rice land as a result of cultivation and consequent aeration during the dry season.

Rural Finance.—The after-the-war business relapse, common to the whole world, does not alter the fact that the Filipino people have increased in wealth steadily during the past two decades. This increasing economic strength has been a very important factor in the steady increase in rice production. The most obvious and direct way in which it has done this has been by an

increase in the number of work animals, but it operates also in a variety of other ways—through the greater efficiency of a greater and better-nourished population, and the better and more extensive farming made possible by more money and better credit. This kind of improvement will continue. It can be facilitated and ensured by improving the credit status of the small farmer. If he has no seed, he is likely to get a cavan for two cavanes of his crop, and his other borrowing is on similar terms; but no industry can thrive and pay one hundred per cent interest. When he harvests, he must sell, always on the worst of markets. A system by which he could warehouse his crop and borrow on his warehouse receipt, as the Javanese rice grower does in effect, would bring him a much fairer return and let him practise better farming. The Javanese system, providing at once for credit and for the economic distribution of the crop, would probably be worth as much to the rice industry of the Philippines as a governmental irrigation system.

Work Animals.—It has just been noted that the Philippine rice production has increased as the former serious dearth of work animals has been partly overcome. The Filipino's way of cultivating rice land is to use the carabao, an animal, as it is to-day, evolved in particular adaptation to this use. Carabao are much more numerous than a decade ago and also very much more expensive. Further increase in the supply of beasts, and the lengthening of the season for this work by irrigation, are the most promising means of improving the preparation of paddy land. The cultivation preliminary to planting upland rice offers more room for improvement than that for lowland; and the upland planter is more independent of the carabao.

Machinery.—Machinery is the trade mark of present Occidental agriculture. The most outstanding features of Oriental and tropical agriculture, when first seen by the American or European traveller, are the absence of machinery, the relative absence of work animals, and

the direct dependence upon human hands. The colonist official is tempted to picture the benighted native lifted out of his squalor by the myriad instruments, methods, and products of the white man's civilization. In the attempt to do the lifting, he passes through the stages of sympathy, of abusing the stupidity of the natives, cursing their obstinacy, and respecting their conservatism. Finally, he realizes that four or five millennia of intensive rice culture have long since developed practice which fits the conditions, and integrated the whole system of rice growing with everything else in the lives of the people so intimately that the units of the whole structure are hard to disturb; and ought not to be disturbed without much more than a superficial idea of the probable results.

As to even the use of work animals: it has just been noted that they are needed in the Philippines, and that in proportion to their abundance rice is grown in greater quantity and more easily. The Philippines are not densely populated, for the Orient. It does not at all follow that animals could be used to advantage in China, Japan, and Java. It is a general, though not universal, condition in the latter countries that the land is kept busy feeding men, without a surplus for beasts. Thus beasts are a very important help in some places and an undue luxury in others.

It is equally unreasonable to presume that machines are everywhere equally desirable. Cabaton [1] says of the Javanese:

> In vain have the Europeans tried to teach the Javanese to mow or reap his rice; he obstinately insists upon cutting it ear by ear, according to tradition, with his little curved knife, which he handles with rare dexterity, but like a man not pressed for time. He refuses even to adopt the sickle used in Sumatra.

Cutting the heads only, done in Java just as commonly in Philippine upland rice, is not only the

[1] Cabaton, A., *Java, Sumatra, and the Dutch East Indies*, London, 1912, p. 215.

most saving of all ways of harvesting, and a handy means of keeping the variety uncontaminated; it is tied into the customs in subsequent handling of the crop, and cannot be changed by itself.

On rice paddies, as they are, machinery of any size practically cannot be used. A fair proportion of the paddy land is level enough so that the single paddies might be large enough to permit machinery to operate, so far as physical obstacles are concerned. Better preliminary cultivation would be likely to result. But no machinery could provide the perfect tilth and levelness achieved by the methods in use. Without the perfect level, the dikes are too low; raise them, and there may not be sufficient water to fill the checks—more water is required to irrigate one large check than for the same area in small ones, aside from the fact that it must be deeper on rough ground; and if there is enough water, it will have to be held deeper than has been found to produce the best crop. Another consideration is that 43 per cent of the cultivated area of the Philippines is in farms of less than one hectare, and only 5 per cent in farms of more than five hectares. The average size in Japan is one *cho,* practically one hectare, or two and one-half acres. And in both countries the holdings of rice land are smaller than the average for all crops.

In my opinion the cultivation of Oriental rice paddies by machinery is at present altogether impracticable. The Filipino or Japanese is too eager rather than too slow to seek help from machines not proved fit for his work. I have seen no few tractors in the Philippines abandoned to rust, which had never done work enough to pay the freight; and cannot read without misgivings when Camus writes that "The scarcity will be less important very soon when a greater number of farmers use tractors," nor sympathize with Yokoi[1] in his apparent regret that "Farmers do not venture to

[1] Dr. Yokoi, "Agricultural Economy of Japan," *Monthly Bull. of Agric. Intelligence*, 4. (1913), 332.

purchase efficient farm implements of modern type, as they are too expensive and they might not pay."

It is upland rice culture, if any in the Orient, which invites the introduction of machinery. The ground is worked dry, commonly free of stumps and snags, and nothing except eventual smallness of the field is a natural obstacle to the use of tractors and gang ploughs. Incidental difficulties are remoteness from sources of machines, parts, and supplies, high cost of fuel, and unfamiliarity of labour with machinery. The last of these difficulties, at first even more serious than delay and cost of parts, tends to disappear. But even small tractors and the associated machinery are very expensive, measured in terms of the wealth or annual business of the Filipino, Javanese, Chinese, or Indian who cultivates upland rice. They are also far from cheap judged by the service they are likely to perform in a year. The use of small mould-board ploughs, made specifically for local use, to be pulled by single bullocks or carabao, as an improvement on the primitive implements which hardly do more than stir the ground, has spread widely in recent years, and has improved the cultivation very materially.

Seed-drills could certainly be used with great advantage. The germination and establishment of seedlings dependent upon rain for their water is very precarious unless the seed can be regularly and certainly put into, not onto, the ground. Hand-seeding in furrows is too laborious to be general practice, even if its cost could be ignored, and accomplishes the purpose at best less perfectly than drills would do. The use of drills spaces the rows uniformly and so facilitates weeding, plants the seed to a uniform depth and so ensures uniformity of germination, in time and space, effects a real economy in the amount of seed required, and is much cheaper in operation than any other method which effectively gets the seed into the ground at all. Drills are simple machines, not dependent upon particularly skilful or careful handling, nor normally subject to rapid depreciation. To fit

small fields and local means of traction, drills must be small.

The use of binders in the Orient, and particularly in the Philippines, has been recommended over and over. They are worth using in the Philippines if anywhere in the Orient, for the Philippines are second only to Japan in the price of labour, and relatively little Japanese rice is on land which would permit their use. Binders are purely labour-saving machinery. Unlike good ploughs and various other machines which improve the work at the same time that they save labour, binders do not do this. On the other hand, they are very expensive in that they depreciate rapidly without expert care. Even on hard ground they are never operated in California rice without three good horses, such horses as are unknown in Oriental agriculture. If driven by ground power, they must move fairly fast in order to operate well. If speed of the sickle bar were accomplished by high gearing, it would increase the power needed to pull them; and the use of auxiliary engines would add materially to the expense directly in operation and in depreciation. The power to move binders satisfactorily is not available in the Philippines nor in any other Oriental rice country. It might be developed by the use of fast Indian cattle, but small tractors would probably furnish the best prospect.

Recognizing them as purely labour-saving devices, binders may be called for by the high cost of labour or by its scarcity. There are no reliable statistics to justify any positive and general statement as to the wage which justifies their use, but I am quite sure it would be more than two dollars a day. Any such wage for farm labour is unheard of anywhere in the East. The use of binders would have therefore to be justified by the scarcity of labour, by their increasing production by making it possible to harvest greater areas. Assuming means to operate the binders, this would be possible if there were greater areas to harvest. Land is not at present a limiting factor in the Philippines.

But the labour supply limits area at other times as well as in the harvest, and before binders can be justified by a sufficient increase in area, there will have to be corresponding changes in other practices besides the harvest.

The inherent evil in the use of binders is their wastefulness, as has already been emphasized in the discussion of California rice. If the inevitable waste in binding be reckoned as low as 10 per cent, which might not be too low with upland rice in the Philippines, and the cost of binding by machinery be reckoned as one-third of that of hand cutting, then, taking waste into account and assuming that cutting by hand entails no waste of rice, binding and hand cutting are balanced in real cost if harvest can be performed by hand for 15 per cent of the crop. If hand cutting cost, instead of three times, twice as much as binding, which is a fairer guess for the Philippines, the two would balance if the hand harvest cost 20 per cent of the crop. The fact is that it usually costs decidedly less than this. Even where labour is locally scarce, the cutting is likely to cost as much as one-fifth only in case the crop is poor; and as one reckons with poor crops, economic weakness bars the use of imported machines, subject to rapid depreciation, more and more completely.

There are still other considerations. For example, if the use of binders, considering waste, is equally expensive with cutting by hand, the latter is preferable practice for the sake of the greater resulting economic strength of the community.

Rice in the Orient has always been cut by hand. Varieties especially prone to shatter have been avoided; but a degree of looseness which would entail excessive loss in binding is relatively harmless, and can be quite overcome by a little extra care when the rice is cut by hand. Real tightness of grain has been an inconvenience when the grain had to be tramped out, or beaten out, or torn out by hand. Philippine rices must therefore be expected, as a rule, to shatter too badly to be sus-

ceptible in practice to binding by machinery. This is no mere presumption. Very many Philippine rices have been tested at the U.S. Rice Field Station near Biggs, California. Most of these failed to mature; but of those that did, there was not one with grain tight enough to make binding feasible. I have found a number of Italian rices unsuitable for binding for the same reason; and it is to be expected as a general defect wherever there has been no selection of varieties which can be bound violently.

On the other hand, there are times when binders, by effecting promptness of harvest, would save more than they would waste. The loss of a crop makes a profound impression. The use of machinery to replace hand labour always appeals to the imagination. And a certain economy of labour, in a land where wages look high, because men remember when they were very much lower, makes so strong an appeal that it easily blinds one to contrary considerations. But my own seasoned belief, based on familiarity with Philippine conditions and experience with binders where we must use them, is that they offer very little immediate promise in the Philippines, even with upland rice. And if their use is not expedient there, it cannot be recommended in any Oriental rice country.

As farm machinery will not have to be discussed further in connection with Oriental rice, it may be noted here that the French have tried it in Indo-China. According to the earlier report by Main,[1] the land chosen turned out to be too low to give the best prospect of success; the machines persisted in developing defects; much time was lost in making repairs; the rains came at their own pleasure; the labourers left in a body when the crop was near maturity; the birds did the harvesting; and the engineer in charge returned to France without heart or taste for renewed experiments. It was demonstrated, apparently to the satisfaction of the

[1] Main, F., "La Culture mécanique du riz en Indo-chine," *Journ. d'Agric. Trop.* 12. (1912), 321.

Annamite natives, that rice paddy could be cultivated with traction ploughs. It was found that the dense growth of reeds covering the lowlands adapted to rice culture could be gotten rid of promptly by mowing them below the surface of the water by machinery. And plots sown with a drill aroused the interest of the neighbours by their excellent showing in comparison with adjacent transplanted plots. Main was encouraged by the results, and was right, for 1 per cent of real success will in the long run outweigh 99 per cent of failure.

A brief account of the continuation of the experiments is given by Ringleman in *Journal d'Agriculture Pratique*, 84. (1920), 94. Official tests of mechanical ploughing in 1917 gave poor results for a similar variety of reasons, chief among them an unfortunate choice of the apparatus used. Rice was harvested with a binder, which it was found possible to draw with a large tractor. Magen [1] gives a still later report on the same work. Under suitable conditions a caterpillar and wheel tractors did good work. The complaint that the wheel tractor could not get traction on moist, clean ground should be curable by the use of proper lugs; so equipped, a wheel tractor is less likely than a track-layer to slip. After the rains began, the tractors went on working in a foot of water.

There is a report, which I have been unable to trace to its source, of successful tractor ploughing in Siam. It says that 15-h.p. tractors ploughed 2·5 acres a day, and did this materially cheaper than it could be done with bullocks. How the cost was calculated is not stated.

Contrary to Cabaton's intimation, the Dutch do not use machinery to cultivate or harvest rice, even on the grounds of their official stations, much less urge the natives to use it.

[1] Magen, R., "De l'utilisation des tracteurs en Cochinchine," *Bull. Agric. Inst. Scient. Saigon*, 2. (1920), 225.

CHAPTER VII

RICE IN OTHER LANDS

The general features of Oriental rice culture, with sufficiently full descriptions of the chief features common to the whole East, having been presented in the preceding chapter, and the practices differing most widely from these having been set forth in Chapter V., it will suffice to treat the rice culture of other lands more briefly, however much more extensively the industry may be developed. Under each, such information as is available regarding production will be given and the known local exceptional features will be described.

INDO-CHINA

The "Indo-Chinese Union" comprises Tonkin, Annam, Cochin-China, Cambodia, and the Laos Territory. The dominant race is the Annamite, numbering with mixed strains some fifteen millions. There are also a million and a half Cambodians and perhaps two millions of very diversified other races. Among these are mountain people, who raise rice in temporary clearings,—the *caingins* of the Philippines—and others whose industry is chiefly pastoral. The presence of these last is notable because, while the lowlands have been swept like the Philippines by epidemic cattle diseases, it has been possible to restore the stock with comparative ease and cheapness—a fact primarily responsible for the constant production of a surplus of rice for export.

Rice is the chief crop of all of Indo-China, but the physical and economic conditions are different in different parts. Leaving the sparsely settled and economically undeveloped interior out of account, there remain effectively two regions: first, Tonkin and Northern and Central Annam; second, Cochin-China with the adjacent parts of Annam and Cambodia. The former is exceedingly like the Philippines, with a better development of Chinese methods in the north, a better supply of buffaloes and cattle for field work, and a somewhat better prospect of a good supply of controlled water when engineering works already undertaken or planned in detail shall have been completed. The climate permits two crops of rice a year, but they are rather precarious. There is some diversification of agriculture, and the population is fairly dense in proportion to the cultivated, if not to the total area. Decade by decade the production has increased, but the increase has only about sufficed to meet the growing domestic demand. The annual export was figured at about 160,000 tons (rice) from 1905 to 1914, and at 180,000 tons in 1921, the record year for Indo-China as a whole. The population is something over six millions, and the domestic consumption cannot be much less than one million metric tons.

Cochin-China has a total area of 20,000 square miles, of which nearly one-third, fully 90 per cent of the area cultivated at all, is in rice. The population is some three millions. It has a dry dry-season. But its wet season is reliably wet; it is out of the usual path of the typhoons, which may bring a heavy rainfall with comparatively little usable water; and the floods of its great river, the Mekong, come likewise regularly. It raises but one crop a year, but that one, as rice crops go in the absence of great engineering works, is safe. The most of its provinces produce no crop except rice. With its small area and population, Cochin-China quite regularly produces more than a million tons of rice a year for export, being second only to Burma as a source of rice for international commerce.

Except for rare bad or exceptionally good years, this margin for export increases steadily. From 1886 to 1890 the average export (from Indo-China) was 495,000 tons (presumably English); from 1911 to 1915, 1,133,000 tons; from 1916 to 1920, 1,287,000 tons. In 1921 it reached 1,720,000 metric tons. About half goes normally to Hong-Kong, the remainder to France and her colonies, Singapore, Japan, Java, China, and the Philippines. There is reason to expect that the export will increase for many years, as the services of the Government become more fully effective, increasing the yield per hectare, and an increase of population brings more land into cultivation.

The most peculiar local feature of Indo-Chinese rice culture is that of floating rice, as it is described by Tran-van-Huu.[1] This rice is native in Cambodia, and is an important product there in the provinces of Battambang, Kompong-Khom, and Preyveng. Fifty to sixty thousand metric tons of the crop of such rice is exported annually from this district. There are no detailed accounts of its culture in Cambodia, nor of the varieties there. It was introduced into Cochin-China about 1900, and immediately showed its particular fitness for lands subject to overflow too deep for ordinary rice culture. By 1906 ten varieties of it were being grown in Chaudôc. The number of these had dropped to six in 1920, but the extent of the culture was still increasing. It has become the chief local product, amounting to 115,000 to 130,000 metric tons a year. While the floating rices may " n'ont qu'une faible importance "[2] (amount to but little) in an Indo-Chinese sense, these figures are fairly imposing compared with Occidental rice production.

The accounts of this rice do not agree altogether. As described by Tran-van-Huu, the initial treatment is like that of upland rice. The ground is prepared in the

[1] Tran-van-Huu, "Note sur la culture du riz flottant en Cochinchine," *Bull. Agric. Inst. Scient. Saigon*, 2. (1920), 46-54.

[2] *L'Agriculture en Indo-chine*, p. 8, Paris, 18 rue Séguier, without author or date, but including 1921 statistics.

same manner, *i.e.* worked dry. The seed may be broadcasted or planted in drills or hills. It may even be mixed with maize, which is then planted a fortnight before the rice so as to be ready for harvest in advance of the floods. For perhaps two months the growth is like that of ordinary rice, the most noticeable peculiarity being very free tillering. Then the floods begin. As the water rises the rice keeps pace, growing at times remarkably fast to do this. The stem internodes grow very long, and are enclosed by sheaths only at their bases, and roots are sent out into the water from the nodes. The usual depth of the water is not more than 1·5 metres, the rice reaching a considerably greater length, since it grows enough so that the upper end floats instead of standing up. But the water may become much deeper, even in excess of 4 metres, without injuring the rice, at any rate as long as the rise is not too rapid to let the tips of the leaves reach the surface.

According to the account in *L'Agriculture en Indochine*, when the rice is ripe, "le cultivateur s'en va sur une légère embarcation recueillir les epis." Kikkawa [1] describes "giant rice," both wild and cultivated varieties in Siam, growing to lengths of 2 metres or much more, slender and naked-stemmed, lifting its panicles high above the water, and harvested by the use of boats. Similar rice is known also in Bengal.

In Tran-van-Huu's account the floods recede gradually in due time, and the rice settles as the water falls. Finally, the prostrate stems and tops settle in a mass on the mud. Then the rice roots anew at the upper nodes, the tops bend upward, the basal and middle parts of the stems die and decay, and the tops are left as independent plants. By sending out branches from more than one rooted node near the top, a single original culm may produce several plants. The original upper end of each culm, and these numerous branches from

[1] Kikkawa, S., "On the Classification of Cultivated Rices," *Journ. Coll. Agric. Tokyo*, 3. (1912), 11-108, p. 16.

the nodes, all produce panicles, so that altogether the yield is heavy—80 to 150 *gia*, or 1920 to 3600 kg. per hectare. The sowing is from March to May, and the harvest in December or January.

All of the varieties of floating rice shatter badly, and all contain some red rice. Some are said to be entirely red, and to be bought as such by the Chinese. One of the cultivated varieties is glutinous, but not odorous. None of them are in much local esteem, because they are not savoury. But the grain is large, and they have found an export market and a demand tempered only by the presence of red kernels. These are reported to be becoming less numerous as a result of selection by the growers.

While Indo-China has long been important as a matter of quantity in the world's rice business, its rice has had no standing as a matter of quality, and has had to be content with a price based on its merely being rice. Carolina, Patna, Siam Garden, etc., have sold by name at prices of their own, but the name of Saigon attached to rice has never been a compliment. The worst that has been true of Indo-Chinese rice has been that it was mixed, not that it was all poor or mostly poor, but that it was so handled that it was impracticable to secure the better varieties or qualities by themselves in sufficient quantities to establish a market. The growers sold to middlemen, usually Chinese, who loaded the rice indiscriminately into boats. These Chinese country buyers are a peculiar institution of many Oriental lands. They know the growers, usually lend them money in advance, may gouge but very rarely cheat them, and are sure of their rice. When it reaches the mills already mixed in the boats, the mills are likely to have no better course open than to mix the boatloads. One writer, exasperated by futile efforts to get the rice to the mills unmixed, charges the buyers with mixing it so that it might reach China at a low price. This is most improbable for several reasons, one of which is that there is an ample market in China for rice of particular quality.

In undertaking to improve this situation the first task of the Government was to identify the best rices. A very large number of samples were collected and examined and to some extent classified. The beginning of such work was about 1909. By 1913 the Government was ready to undertake it methodically and extensively, and proceeded with a careful study of the methods used in Java in selection and breeding; but the war checked progress during the next five years. Such work is now entrusted to an active "service of genetics." It maintains a laboratory for rice selection in Saigon, a central rice station in Cantho, a trial garden at Phu-my, and other recent ones serving primarily for the multiplication of approved strains, as well as for the test of local fitness, at Cau-Ke, Phung-Hiêp, and Soctrang, besides two in Tonkin.

Of a considerable number of varieties, native and imported, subjected to comparative test, two, *Huê-ky* and *Ra-may*, have proved best, considering both quality and yield under prevailing Cochin-Chinese conditions. These have been pedigreed and multiplied, and about eighty tons of seed a year have been given out at the current commercial price of paddy. From this, at least where double transplanting is practised, a full hundred-fold increase is not merely hoped for, but confidently expected. The growers have taken to these pure strains with an eagerness shown by applications for four or five times as much seed as the stations could distribute, and by their selling their crops in turn for seed, even under newly invented names. The last compliment is not welcomed by the service of genetics nor by the mills, as it places a new difficulty in the way of standardization. A proposed way of discouraging the invention of new names was to offer a premium to producers of the two favoured varieties. But a far better course, if it can be maintained, has been the offer by two of the milling companies of a slightly higher price for rice accompanied by a certificate of variety issued by the service.

The origin of Huê-ky is interesting.[1] The name means "American." An Annamite merchant of Travinh found his lamps, imported from the United States, packed in rice straw. This happened to contain some grains of the rice, which so pleased him by their appearance that he picked out what he could and planted them. The second planting yielded at the phenomenal (for Indo-China) rate of 6900 kg. per hectare. The first report on it was made by a missionary in 1908. Its yield at Cantho is given as 3851 kg. It ripens in February after a growing period of more or less two hundred days. It is a tall rice with very tight grain and is notably resistant to drought and disease. Two tons sent to France in 1916 was appraised as superior even to Spanish rice. Statistics on the grains are: length, 7·8 mm.; width, 3·3 mm.; thickness, 2·07 mm.; weight of one thousand, 29·68 g.; hull, 19 per cent. The data given do not permit its satisfactory identification with any American variety.

Tests of Javanese rices at Cantho indicate that grain characters can be expected to come true in the new country, but that the agronomic behaviour may not safely be anticipated. The Javanese introductions were quite unsatisfactory in yield.

The Government has also demonstrated the value of fertilizers and tried to stimulate their use. It had no success at first in the latter effort. But the discovery of domestic phosphatic deposits cheapened them enough so that their use is now regarded as an appreciable factor in the increase in yield per hectare. This yield was estimated a decade ago at about 950 lb. of finished rice an acre. The usual run of paddy milled out a little over 60 per cent of its weight in clean rice. Before the milling business became concentrated in the big mills in Cholon, the practice of the small country mills, instead of buying paddy for cash, was to pay for it by return of

[1] Robin, J., "Les différentes variétés de riz cultivées à la station de Cantho," *Bull. Agric. Inst. Scient. Saigon,* 1. (1919), 347, 2. (1920), 40; Tran-van-Huu, "Note sur la variété de riz dite Huêky," *ibid.* 2. (1920), 75.

half of its weight of milled rice. This was so profitable that they managed for a time to make it quite difficult for the foreign-owned mills to secure paddy.

Attention has also been given to the pests of rice, and more than forty insect enemies have been identified. *Cnaphalocrocis*, said to be locally the commonest of the stem-borers, is especially destructive in the second crop (tenth-month rice) in Tonkin, where the damage runs from 5 to 25 per cent. In Cochin-China, while common, it is considered by Vincens to be much less destructive than *Schoenobius* and *Chilo*. The rice bug, *Leptocorisa*, is said to be destructive everywhere. It is not reported that advice has so far had appreciable effect on native efforts to control the pests.

The first economic efforts of the French administration, dating back to 1880, were aimed at the control of water. This involves a variety of problems, all related to the production of rice: construction and maintenance of canals—practically the only means of transportation in the chief rice-producing territory,—control of floods, irrigation, drainage, and the control of salt and brackish water. In all of these fields, especially in the canalization of the delta of the Mekong, the accomplishments have been very real. The irrigation programme, going forward at present by contracts made in 1921 and extending to 1926, covers projects officially adopted for the irrigation, by gravity or by pumping, of far more than one million hectares. The average estimated cost of installation per hectare is decidedly lower for the pumping projects than for those by gravity. There is a large area in which irrigation with fresh water can be controlled by the rise and fall of the tides.

Cholon is the great milling centre, and Saigon the point of export, the two having grown to form practically one city. A notable feature of the Indo-Chinese export is that almost no rice goes abroad without first being milled white. A relatively considerable part of the export trade from Burma is still "cargo rice," partly milled to reduce the bulk, but not even entirely free of hulls.

SIAM

The rice industry of Siam is essentially a duplicate of that of Cochin-China. The population and domestic consumption are greater, rice is not quite so nearly the only crop, and the crop has not been quite so reliable nor the average export quite so great. Production, consumption, and export have all increased greatly during the past half-century. The growth of the export business is shown by the following table: [1]

EXPORTS OF ALL GRADES OF RICE FROM SIAM

	Long tons.
Average 1860–69	100,000
„ 1870–79	155,000
„ 1880–89	260,000
„ 1890–99	460,000
„ 1900–09	760,000
„ 1910–14	878,000

1921 was a record year in Siam as in Indo-China, the export reaching 1,700,000 tons. The estimated area in rice that year was 6,150,000 acres. 300,000 acres of this was reported as irrigated. Some large irrigation works have been established in the last few years, and work is going ahead. The yield per acre was formerly believed to be higher in Siam than in India and Indo-China, being estimated at 1120 lb. of clean rice in Siam; but Indo-China is probably ahead in this respect at present.

The milling business is concentrated in and around Bangkok, in which district eighty large mills were in operation in 1921. The export is very largely of white rice, whole and broken, the latter chiefly to Hong-Kong. Three-fourths of the export is to Hong-Kong and Singapore, largely of course for re-export from both places. The export from Siam may be expected to continue to increase.

[1] This and most other statistics in this chapter applying to years not later than 1916 are taken from the *Indian Trade Enquiry Reports on Rice*, published in 1920 by the Imperial Institute.

INDIA

While India is one of the foremost wheat-producing countries of the world, and produces a number of other cereals in very imposing quantities, rice is still by far the most important crop of this populous empire, both in production and in consumption. During a considerable part of the time that rice has been an important article of world commerce, the territory now included in the Indian Empire has exported more than half of all that entered international trade. This position of eminence over the other lands combined it seems to have lost, and may not regain it; for in recent years the more rapid increase of consumption than of production in most parts of the empire has tended to provide a domestic market for more and more of the surplus from Burma; the opportunity for a great increase in acreage to meet the needs of a growing population is not as good for rice as for some other crops; and with increasing economic strength the population must be expected to turn more largely to the staple it regards as the best, and make a staple of what is now in parts of the empire a luxury.

The acreage and production during the year 1916–17 in the several provinces, including the native states, is shown in the following table:

	Acres.	Production.		
		Total.	Per Acre.	Per Capita.
		Tons.	Cwt.	Cwt.
Bengal	21,120,000	8,028,000	7·6	3·5
Bihar and Orissa	16,442,000	8,898,000	10·8	5·2
Madras	11,377,000	5,536,000	9·7	2·7
Burma	10,520,000	4,417,000	8·4	8·3
United Provinces	7,156,000	2,675,000	7·5	1·1
Central Provinces and Berar	5,086,000	1,481,000	5·8	2·1
Assam	4,265,000	1,406,000	6·6	4·2
Bombay	2,430,000	1,094,000	9·0	1·4
Sind	1,220,000	490,000	8·0	2·6
Coorg	84,000	54,000	12·9	6·2
Total	79,700,000	34,079,000	8·6	

The figures in the last column are of particular interest in connection with the questions to be discussed later as to the economic status of the rice industry and of probable future supplies for export. Burma raised approximately one acre of rice *per capita* of the population, no other province except Assam having more than half an acre. In the two preceding tables both tons and hundredweights are "long," of 2240 lb. and 112 lb. respectively.

Burma.—From the same source as these tables are taken the following notes from a paper by McKerral, contributed to the International Congress of Tropical Agriculture in 1914:

Burma has three climatic zones: (1) a southern tract with 70 to 200 in. of rainfall, (2) a northern area with 60 to 100 in., and (3) a central or dry area with 25 to 35 in. The main crop is from the first area, embracing the deltaic plains, where the soil varies from a sandy loam to a darkish clay of lateritic origin. Owing to the rapid hardening of the soil after the rains are over, the cultivation can only be by means of irrigation. Manuring is done in the nurseries, but scarcely at all in the transplanted fields. Only cattle manure is used, green manuring being impossible owing to the soil and the sudden approach of the monsoon; weeds, however, are ploughed in when possible. Four main varieties of crops are recognized: (1) early, maturing in 75 days; (2) medium, maturing in 75 to 100 days; (3) long-lived, up to 120 days; (4) glutinous varieties, used for special purposes, and never exported. The short-lived varieties are grown in the higher lands of the deltaic region, the long-lived in the lowest lands. The reaping of the main crop is done in December and January, largely by coolies from Madras and Bengal.

Mr. McKerral put the yield in Lower Burma at 1500 to 4000 lb. of paddy (say 8·4 to 22·3 cwt. of cleaned rice) per acre. According to the Indian crop estimates for 1916–17, the average yield of rice throughout Burma was 8·4 cwt. per acre, against an average yield of 8·6 cwt. for India as a whole. Cropping is continuous, and there are no rotations, with the result that the natives complain of declining yields. Hence Mr. McKerral reached the conclusion that Burma had arrived, before the war, at the stage of necessary transition from extensive to intensive methods of rice cultivation. This is the more necessary in the interests of Burmese agriculture because there are no competing crops in the great rice-producing area of Lower Burma.

Taking Burma as a whole, the growing of rice there runs through essentially the same range of natural conditions as in Indo-China and Siam, with the same range of practices and the same low average yields. The chief governmental effort to improve the yields has been by the distribution of seed of productive pure lines. The hill-peoples of the neighbouring highlands have their own varieties, lowland and upland, including glutinous varieties, more information about all of which may prove very valuable. Drawing a bamboo sidewise across the field of ripe grain, so as to make all of the stems incline in one direction, is reported as a Burmese device to facilitate the harvest.

Bengal.—The rice culture of Bengal is more distinctive and better known. Still, how incomplete is our knowledge of the rice culture of the foremost rice-producing region as a whole is well illustrated by the fact that a distinguished official agricultural authority, less than a decade ago, made quite impracticable recommendations for the control of a disease in Bengal largely because he did not sufficiently understand the conditions of culture. I make this statement entirely on his own authority,[1] and am indebted to his publication for most of the following information on Bengal rice. Yet Bengal rice was already better known than that of Burma, Siam, or Cambodia—not to mention China.

Although a tongue of the province reaches a sufficient altitude to include Darjeeling, the great typical rice area practically comprises the delta of the Brahmaputra and Ganges, a notably uniform geographical area. It is probably decidedly richer in varieties than any other like uniform area, and the adaptation of varieties to fine details of environment is more perfect here than is known anywhere else. With the neighbouring region, as far as the Central Provinces, this territory is also richest in varieties sharing the characters of wild rices—

[1] Butler, E. J., "The Rice Worm and its Control," *Mem. Dept. Agric. India*, Bot. Series, 10. (1919), 1-37.

colour, looseness, long glumes, etc.—so that, altogether, rice may be deemed to have been native in this territory with more reason than can be found for locating its native habitat anywhere else.

This delta is interlaced with main and minor water-courses, flooded during a part of the year, and providing then fair means of transportation, seriously impeded in part in recent years by the spread of the water hyacinth. Other avenues or means of transportation are wanting. The banks of the river-arms, as is usual in deltas, are the highest ground. As the channels interlace, the country is in effect a group of islands, the central area of each of which is typically the lowest part. It is this difference in the level of the land, determining how deeply it will naturally flood as the rivers rise, when and how long it will be flooded, and to some extent the character of the soil, which determines the manner in which rice can be grown on it and the variety or kind of rice which can be grown there.

According to the time of harvest, the Bengal rices form three groups: [1]

(1) *Boro*, or spring paddy, sown in November to January, harvested from April to May.

(2) *Aus*, or autumn paddy, sown from March to May, harvested from July to September.

(3) *Aman*, or winter paddy, sown from March to May, harvested in November and December.

Of these, the *Boro* is least important, occupying only about 2 per cent of the delta rice area. Growing during

[1] Kikkawa, in the *Journal of the College of Agriculture* of the Imperial University, Tokyo, 3. (1912), 15, says that "according to most authors" the rices of India form five such groups:

	Sown.	Transplanted.	Harvested.
Aus . .	April, May	Not transplanted	July-September
Aman .	May	June, July	November
Boro, Kharif	June, July	July, August	September, October
Boro, Rabi	October, November	November, December	May
Raydra .	December	Not transplanted	September, October

the driest season, it is restricted to the immediate neighbourhood of the permanent watercourses, whence a supply is available for irrigation, and to the lowest areas, where it is naturally easiest to keep water impounded. Except that seed is sometimes sown broadcast on the mud flats of the main streams, all of it is transplanted.

Somewhat more than one-fourth of the area is occupied by *Aus* varieties. On the higher levels it is transplanted; on the lower, usually broadcast. As is true in general of very early rice, the straw is short, the yield not heavy, and the quality not the best. In some places exceptionally early broadcast *Aus* is followed by transplanted *Aman* on the same ground. This is done only on rather low, but not bottom land, where cultivation and transplanting can be performed as the natural flooding begins. On some of the (geologically) newest land near the coast, *Aman* and *Aus* varieties are broadcasted together, and harvested each as it ripens. This is the only known instance of the deliberate mixed planting of rices to be harvested at different times.

About two-thirds of the area is devoted to *Aman* rice. Of this there are in every locality varieties adapted to every level of land, respectively to every depth of water, even to differences of level as little as six inches or a foot, and to differences of treatment in other respects. On the bottom lands the seed is always sown broadcast, because when the time for transplanting arrives the water is normally too deep to permit it, although there are varieties which can be transplanted two feet tall and into eighteen inches of water. The varieties suited to the bottoms must grow very rapidly to keep pace with the rising water—Butler mentions a growth-rate of nine inches a day and a height of twenty feet. There is no report of their exhibiting the further peculiarities of the Cambodian floating rice. On the next levels the rice may be either broadcast or transplanted. As the highest ground is reached, transplanting tends to be

the only practice. Besides yielding most heavily as a rule, the transplanted rice is of better quality. As the highest ground produces the finest rice, there is a constant effort to raise the level even of the single small paddies.

The nematode disease of the rice on the lower levels has already been described. It is a serious menace to this very important rice district.

In view of the importance of the Bengal crop, the Government is naturally making an earnest effort to improve it, maintaining a station at Dacca, where pure-line breeding and hybridization receive attention on a scale second only to that in Java. The chief obstacle to improvement in various ways is the backwardness of the population. A very dense agricultural population devoted to the production of staple crops is almost inevitably poor but very set in its customs, and India is notorious for the rigidity of all its customs. In Bengal these difficulties are confirmed and added to by the extreme lack of roads or other means of communication, even for short distances, except during the limited season when boats can reach all parts of the delta.

Bombay.—A very interesting modification of the usual Oriental practice in transplanting is the specialized method of seed-bed preparation practised in Western India and known as *Rab*.[1] This consists in burning the seed-bed. It is practised from Nerbudda on the north to Kanara on the south wherever quality is a prime consideration in the culture of rice. This area is characterized as a whole as one of very heavy, sticky soil, exceedingly hard when dry and tenacious when wet. Native prejudice in favour of the method is tenacious to the point of claiming that except by this practice rice fit to transplant cannot be produced.

Typically, the procedure is first to cover the prospective seed-bed with a layer of cow-dung broken into

[1] Mann, H. H., Joshi, N. V., and Kanilkar, N. V., "The Rab System of Rice Cultivation in Western India," *Mem. Dept. Agric. India*, Chem. Series, 2. (1912), 141-193.

small pieces; cover these with a layer of branches, twigs, grass, or any other combustible material; cover this with a layer of soil, and burn. The burning is done shortly before the rains are expected. After the rains soften the ground, it is ploughed, cross-ploughed, and cultivated again, and reduced to the smooth and even texture characteristic of good rice seed-beds and then planted. The time for transplanting is said to be about twenty days later. At this time the seed-bed, as well as the other land ready, receives transplanted rice; and the seed-bed produces the finest crop, which is saved for seed.

As variants in the method, for lack of materials, the branches, etc., may be omitted, or the dung may be omitted, but with much loss of effect. The application of an equal amount of dung without burning, which is practised in many other places, is much less effective. Rarely, the seed is planted without waiting for rain to soften the soil, so that it germinates at once when rain comes. If the rain holds off for a long time after the burning, much of the effect is lost. And if it rains heavily and continuously, so as to delay preparation and planting, or a first light rain is followed by weather too dry for rice to start, the loss of effectiveness is greater.

Chiefly because the consumption of brush and tree materials was offensive to the Government's forestry service, which saw in the method nothing more than the use of ashes for fertilizer, *rab* received much study many years ago. The result was a recognition of the fact that while the dung and ashes have a material value used directly as fertilizers, the effect of the full *rab* process is decidedly greater. Mann's rating of the effects, from a carefully controlled study, is that the burnt materials in themselves improve the seed-bed by 80 per cent, but that when they are burnt at the right time and left in place the improvement is 182 per cent. It is not quite clear that in his practice of *rab* the top layer of soil was applied; if it was not, considerable of the effect was

lost.[1] However that may be, his work and that of Knight, which he cites, have proved several matters of interest.

The effective heating of the ground does not reach a depth of more than an inch. Heating to 75° C. is practically without effect. Above this point, up to perhaps 125°, there is a great increase in effect, but very little more in heating above the latter point. The effect begins to wear off within six weeks of dry weather, and is almost gone in three months. The heating increases the immediately available food in the soil, but this cannot be largely responsible for its effectiveness, because an extract of the heated soil applied to other soil is practically without effect. The heating materially changes the physical properties of the soil, depriving it temporarily of its sticky character. Knight says that a liberal use of oilcake, particularly of safflower (*Carthamus*) cake, is fully as good as the practice of *rab*. Safflower cake, and no other kind tested, acts like heating in causing quick clearing of an extract of the soil. Small amounts of gypsum have a similar but weaker effect. If this improves the soil, lime could be applied to the whole field. Heating diminishes the active aerobic life of the soil for a time; then this increases until, six weeks after heating, such activity is much greater than before the operation, after which time it sinks to normal.

The extreme laboriousness of the practice of *rab* is shown by the fact that where the materials to be burnt are not exceptionally abundant or conveniently at hand, the collection of these may keep the villages busy during the whole time from December to May. Either the handling of rice in seed-beds is remarkably difficult in this region, or the quality demanded of seedlings to be transplanted is remarkably high; for it appears from a compilation of older figures by Mann (p. 153) that a

[1] As I know from some work with heated and burnt soils begun years ago in the Philippines, stimulated by the methods of the pepper growers, but never carried through. Heating soil for a given time and to a given degree in an oven or over a sheet of iron does not accomplish the full effect of heating it directly over a slow, smouldering fire.

unit of area of untreated seed-bed will provide seedlings for only two or three times its area of paddy. *Rab* of grass and leaves multiplies this by 1·7; of branches by 2·1; and of cow-dung by 2·4.

In Abder Rahman Ishaq's [1] account of *rab* practice in Sind there is no mention of soil over the burnt material. In the absence of cow-dung the *rab* there may be ten inches of grass or six inches of rice hulls. There is there no dependence upon rain for irrigation; the seed is sown the day after the burning, and the water is turned on at once. To hinder rooting, the bed is not worked, and transplanting is done after fifteen to twenty days instead of after the thirty or more, usual elsewhere.

The improvement of soil by burning is no new thing. It has long been done with very heavy soil in England and Germany. Work at Rothamsted has definitely proved its value, and has added an explanation, in the modification of the microscopic life in the soil, to others already known. It is a minor and incidental element in caingin culture, substantially the practice mentioned by Mann as prohibited in Japan. Investigations by Daikuhara and Hanai, Nagaoka [2] and Aso have established the liberation of phosphoric acid from organic compounds as one explanation of the value of the treatment. Using soil which had been heated to a glow, Nagaoka found that its use alone decreased the yield, but that one part added to three of untreated soil more than trebled the crop. His analyses showed enough phosphorus in the soil used to last for two hundred years, yet a small addition in available form paid well. According to circumstances it might or might not be cheaper to liberate some of what was already present than to apply more as a fertilizer. The bad effect of using burnt soil alone was attributed to its alkalinity.

[1] Abder Rahman Ishaq, "Rice Cultivation in the Larkhana District, Sind," Dept. Agric., Bombay, *Bull.* No. 99 of 1920.

[2] Nagaoka, M., "On the Effects of Soil Ignition upon the Availability of Phosphoric Acid for Rice Culture in Paddy Fields," *Bull. Coll. Agric. Tokyo*, 6. (1904), 263; Aso, K., *ibid.* p. 277.

The burning of soil is familiar practice as a means of stimulating the early growth of pepper. Burning trash where rice seed-beds are to be located is likewise common, for the sake of the ashes and to provide freedom from diseases and pests. The heating of soil also, where combustible material is available, is very likely an improvement well worthy of general imitation.

It is the practice in Sind, if the growth of the rice is very rank, to let cattle graze the tops above the water, or to trim them off with a sickle (Abder Rahman Ishaq, *l.c.*). "This pruning encourages the formation of bigger ear-heads and keeps down the proportion of straw to grain." The range of yields is 7·8 to 26 cwt. of grain and 12 to 32 cwt. of straw. After the threshing (by tramping out by cattle) the straw is baled and marketed. One variety, *Sighro*, is said to ripen in about fifty days. The most highly prized variety is an especially fragrant one, *Sugdassi*. Winter ploughing is practised if possible; spring ploughing must be by puddling, which is bad for any crop planted after the rice harvest. Irrigation by canals from the Indus, and to a minor extent by utilizing the play of the tides, is necessary and well developed, the climate being fully as dry as that of the California growing season.

Austin[1] quotes from Balfour's *Cyclopedia of India* a bizarre account of rice planting in Lower Sind. Irrigation was said to be by the sea, and the only cultivation by the tramping of buffaloes, into the footprints of which the seed rice was thrown, "the men employed in sowing being obliged to crawl along the surfaces on their bellies with the basket of seed on their backs, for were they to assume an upright position they would inevitably be bogged in the deep swamps."

Mysore.—A study of a number of the problems of rice culture in this State[2] has led to some practical conclusions. Tests of dates of ploughing led to the

[1] Austin, A., "Rice: Its Cultivation, Production, and Distribution," U.S.D.A., Div. of Statistics, Misc. Series, *Report* No. 6, 1893.

[2] Coleman, L. C., and Ramachandra Rao, D. G., "Experiments on Paddy Cultivation," Dept. Agric. Mysore, Gen. Series, *Bull.* No. 2, 1912.

conclusion that working the land wet immediately before planting gave better results than dry ploughing after the harvest and leaving the land fallow until the next planting season. This is so contrary to general experience elsewhere, and to what might be expected on the basis of the general principles of soil management, that it ought not to be accepted as even locally established without an explanation of valid local reasons. Freedom from weeds may be a complete explanation, but hand weeding is usually practicable in the Orient. Ploughing eight inches deep proved no better than four inches.

Transplanting produced a more reliable crop than broadcasting germinated seed on wet ground, but the difference was not great. Both gave much better results than broadcasting onto dry ground. In transplanting, two seedlings to the hill were found certainly sufficient. The *raiyats* say they use five or six, but counts showed still more. Considering the low yields the waste of seed is correspondingly great. Castor-oilcake showed itself a profitable fertilizer, as did also the green manures; but ordinary commercial fertilizers increased the crop at a considerable cash loss. Selection of heavy seed by the use of brine improved the crop by 15 to 36 per cent. By "early varieties" one understands here such as mature in 115 to 120 days; such varieties yield poorly. So likewise do the scented varieties, but the latter bring the highest prices. Varieties brought in from other provinces did not do as well as the better local ones.

India in General.—Austin's treatise contains other statements hardly less surprising than that already quoted. For instance (p. 45): "The favourite rice among the natives of Bengal is what is called 'cargo' rice, of large and sweet grain, but coarse and red." More credence may be given to his account of Nepalese *Joomla* rice, which flourishes "seemingly without inconvenience among the snows and frosts of the Himalayas at an elevation of 6000 to 7000 feet." It is broadcasted after germination with manure, and is said to have been

raised experimentally in England. Hooker[1] describes the rice of the Lepchas about Darjeeling as glutinous, with large, flat, coarse grain, grown without irrigation. Rice is treated in Kashmir very much as by the Igorots as regards its culture and the manuring of the paddies, but is raised on comparatively smooth valley floors.

In Central and Southern India rice culture is diversified, in adaptation to a wide range of natural conditions and of density of population; and the studies and reports regarding it touch only the problems which have been first to demand attention. The use of green manures is general,[2] *Sesbania aculeata*, *daincha*, being the most used. This is either ploughed under before it grows too big, or allowed to reach its natural height of about eight feet, when a good stand yields enough herbage to manure four times the area on which it grew. Other legumes planted to improve the soil are sunn hemp, wild indigo, and green gram (*Phaseolus Mungo*).

In most places the green manures are worked in as the land is prepared to receive transplanted rice. In Orissa transplanting is not general, but Basu showed that *daincha* might well be sown with the rice, one measure of *daincha* seed with four of rice. The *daincha* at first outgrew the rice, but when they were four to six weeks old furrows were ploughed across the field. This is usual local practice to reduce the cost of weeding, and is expected to bury the most of the weeds and about half of the rice, but to improve the final crop. What *daincha* remained was pulled and buried by hand at very little expense. The improvement in yield in one of Basu's experiments was 2 maunds 14 seers per acre, and in another, 3 maunds 7 seers, the only added cost being that of the *daincha* seed.

In the Tanjore delta[3] *Marsilea* and *Chara* are

[1] Hooker, J. D., *Himalayan Journals*, i. 123, London, 1855.

[2] "The Cultivation and Preparation of Rice," Part I., *Bull. Imp. Inst.* 11. (1913), 634 (p. 642); Basu, S. K., "Green-manuring of Broadcasted Paddy in Orissa," *Agric. Journ. India*, 16. (1921), 689.

[3] Sampson, N. C., "Some Factors which influence the Yield of Paddy," etc., *Agric. Journ. India*, 14. (1919), 739.

mentioned as weeds which may greatly check the growth of the rice. These are true aquatics, which, like many others of wide distribution, may appear in ditches and ponds almost anywhere, but are in most places unable to interfere with rice. In fact, *Chara* would in many places be welcomed, if given any attention at all, as a plant unable to take anything, even light, from the rice, but likely to improve the vigour of the roots by setting oxygen free. Illustrating the contradictoriness of some of the sweeping published statements about rice in India, Sampson says that transplanting in the Tanjore delta (Madras) usually takes place after about forty days; while Austin says that the "harvesting . . . in this latitude (Madras still) is not more than sixty days after sowing, as a rule."

As noted at the beginning of this discussion, India is not likely to increase in importance as a source of rice for the rest of the world, but will more probably tend to lose its past and present dominance. The acreage has been practically constant for some years, being given as 79,154,000 in 1922, a figure previously exceeded in 1916. For many years before there had been no considerable percentage of increase, while the estimated area in wheat, millet, and other grains increased greatly. The rice area has of course not reached a limit; but the time has come when an increase in production must be looked for primarily by heavier yields. The possible results of such effort may not be forecasted, but except for brief periods they are unlikely to do more than satisfy the increasing local demands. The best effect of such efforts is the economic improvement of the native peoples; and it is uniform experience in the Orient that, with any measure of relief of general poverty, the rice consumption increases, even though the population was supposed already to live almost entirely by rice, and may have been pitied for this condition. There is probably not in India enough land suited to rice to produce enough to satisfy the demands of an Empire of three hundred million people once they

are in an economic position to choose the place it shall have in their diet.

CEYLON

Rice is the chief native crop of Ceylon, the area varying normally between 600,000 acres (1921) and 750,000 (1922); in 1912 it reached 801,024 acres. The yields are remarkably low—less in most years than one thousand pounds of rough rice to the acre, as was usual a decade ago in the Philippines. They show a slight tendency to increase. But no increase in acreage or in yield per acre offers any prospect of making Ceylon produce nearly as much rice as it consumes. Accepting 168,000 long tons of rice as the average domestic production, the imports usually amount to fully twice as much, mostly from India. This makes Ceylon, with a population a little in excess of four millions, and rice as its principal native crop, one of the really important importing countries.

The methods of production are not remarkable except for the inefficiency of their application. The Government has given long and careful study to the export crops—tea, coco-nuts, etc.—but has accomplished little in stimulating or improving the culture of the staple food crop. Ninety varieties were under test in 1920,[1] and in 1923[2] twenty-three pure line selections were being worked on. Eight stations were provided for tests in different places before the release of seed to growers. Summers' study of tillering showed several advantages of transplanting over broadcasting. Two years' experiments with green manures[3] showed them always beneficial, with or without the use of phosphatic fertilizers. As in India, sunn hemp, wild indigo, and *daincha* are recommended.

[1] Summers, E., "The Tillering of Ceylon Rices," *Trop. Agric.* 56. (1921), 67.
[2] Iliffe, R. O., "The Selection of Pure Line Seed Paddy," *Trop. Agric.* 60. (1923), 115.
[3] Stockdale, F. A., "Green Manures for Paddy," *Trop. Agric.* 60. (1923), 119.

BRITISH MALAYA

The incomplete published statistics of area in rice production and trade suffice to show that the Straits Settlements, Federated Malay States, Sarawak, and British North Borneo none of them produce as much rice as they consume. The net imports are usually more than 150,000 tons to the Straits Settlements, still more to the Federated Malay States, and 10,000 tons or more each to British North Borneo and Sarawak. The whole of Borneo is effectively non-productive, except for the home use of the "wild men." Leaving out of account Singapore, with its heterogeneous population of rice eaters, this importing trade has developed with the growth of the plantation industries. While the population has increased naturally and by immigration and the importation of labour, the rice area has rather decreased where the influence of the plantations is felt. Labour is expected to be, and usually is, more remunerative when applied to rubber and coco-nuts than when devoted to rice; the result is that rice tends to be ill-attended to, and the yields per acre to decrease. Figures given me by Mr. M. D. Knapp, of the United Rubber Plantations Company, show that the labour applied to rice, lowland and upland, is surprisingly inefficient.

The economic condition which results from the supplanting of rice by export crops of other kinds is decidedly unsafe. Let the market for the export crop fail, and the resulting condition is at once worse than the prevalent Oriental poverty. Government in Java, Japan, and the Philippines has therefore done well in giving its keenest attention to stimulating the production of rice. The market may slump as it will, where rice itself is the export crop, without serious consequent suffering. But where other crops must furnish the money to buy foreign rice, hunger may enter promptly when rubber, tobacco, coffee and tea, and copra cannot be sold.

Seed selection is being practised at Kuala Kangsar.

Extensive irrigation works in Perak (Krian) resulted promptly in doubling the local rice production and making it profitable. 56,000 acres are served; and the Government now guards zealously against any destruction of rice land in the course of tin mining.

A paper by Jack,[1] received just as this work is finished, gives a full and interesting account of rice culture in the Malay Peninsula. Statistics on area and production in the chief rice-producing states are :

	Area in Rice.	Population.	Area per Capita.	Yield per Capita.
	Acres.		Acre.	Gantangs.*
Kedah . . .	174,000	338,558	0·51	130
Perlis . . .	31,000	40,087	0·77	133
Perak . . .	119,505	559,055	0·2	35
(Krian)			0·64	161
Kelantan . .	175,050	309,300	0·53	105

* Roughly, gallons.

"In Malaya over 99 per cent of our population depends entirely on rice for their subsistence, and yet the country only produces approximately two-fifths of our annual consumption. Furthermore, only 16 per cent of the population is engaged in rice cultivation."

The average yield of the whole country is 203 gantangs per acre, and only one-fifth of an acre *per capita* is grown. It is estimated that 0·62 acre would be required to make the people self-supporting. The deficit is due to the non-Malay population engaged on plantations and in tin mining. The disposition of the Malay is to raise his own rice, but no more than this, unless he can make more money in this way than in any other.

[1] Jack, H. W., "Rice in Malaya," *Malayan Agric. Journ.* 11. (1923), 103, 139.

Transplanting is either by hand or by the use of an implement called *kuku kambing* (goat's foot), which obviates stooping; with this six women plant one acre a day. The usual spacing in Krian ranges from 15×17 inches in good land to 10×10 in poor. Where the water is more than ten to fifteen inches deep the tillering is checked, and closer planting is called for. One weeding six to eight weeks after transplanting is sufficient on good land. On poor land two or three weedings are necessary, because the rice does not grow fast enough to smother the weeds. *Seraup*, an eight-months variety, averages 18 to 20 culms on good land, and may reach 50, but may average only two or three on poor soil. A plant can be divided several times to fill blanks, and will promptly replace the culms removed (? plant or hill).

The Malays harvest the rice head by head; a woman can harvest 40 gantangs of paddy a day. On the northern west coast the Tamils contract much of the harvest at about 15 per cent, and cut the rice with a serrated sickle at the rate of three-quarters of an acre a man a day. The harvesting and the threshing are performed rain or shine; in fact, rain is liked for the threshing. Winnowing is done with the common flat basket, or with a hand machine introduced through Siam from China, which blows the chaff from the falling grain by means of a fan.

There are ten large mills, one operated by the Government, which breaks the Chinese monopoly of milling. Almost all of their rice is "parboiled" before milling—heated for ten minutes in steam under a pressure of twenty pounds. The Indian immigrants prefer this rice, as it is easily cooked and they like the flavour. About 10 per cent, intended for the Chinese, is not so treated. The tendency is for the plantations to put in their own small mills.

Of pests, rats and birds are everywhere. *Tylenchus angustus* occurs in the Krian district, and damages the roots and young shoots. *Leptocorisa* and *Nephotettix* suck the leaf sap, the latter injuring young rice especially.

Podops coarctata, a black bug half an inch long and slightly narrower, sucks the sap from the base of the plant, and lives over in the stubble. It can be eliminated by flooding. *Diatraea auricilia* and *Schoenobius* are listed as borers ; *Parnara, Nymphula, Melanitis,* and *Spodoptera pecten* as leaf eaters. *Gryllotalpa borealis* destroys seedlings on ground not submerged. *Calandra, Sitotoga, Ephestria, Tribolium castaneum,* and *Silvanus surinamensis* are listed as pests of stored grain.

JAVA

As in all the Orient, rice was the original crop of Java, which supplied its own needs before the modern development of commerce. The change in this respect came a century ago with the forcible interference of the Government in the industry of the people, first by Daendels and Raffles, and then by the establishment of the Cultuur system by van den Bosch. Under this system the planting and production of a variety of exportable crops was compulsory, on a large scale, with resulting financial profit to Holland and the Dutch, and inevitable neglect of rice culture. Appeals to the better sentiments of the Dutch people were effective after a terrible famine in the district devoted to sugar demonstrated the effect sure to result sooner or later, from a cultural system which sacrifices sure food for probable money. The system of forced culture certainly is entitled to the credit of establishing a diversification of agriculture, without which Java could not support its present population and efficient Government; but it did this in a way which will not be repeated as other lands attain the same end. And the Government of the Dutch Indies now sets an example to the world by its active and effective promotion of agricultural industry in enlightened and sympathetic harmony with the welfare of the native population.

The population of Java (and Madura) is not far short of forty millions, having multiplied by six or more in a

century. It exports sugar, coffee, and tea on a great scale, practically all of the quinine of commerce, and tobacco and a variety of minor products. It even exports rice, normally 50,000 tons or more, largely *Carolina* or its equivalent, at a much higher price than it pays for what it imports. But the production of rice has not caught up with the consumption since the introduction of diversified agriculture, and the density of population now makes it improbable that it will be able to do so. Java and Madura import more or less 300,000 tons a year, and the other Dutch Indies, chiefly Sumatra, an additional 200,000 tons. Necessarily, this comes ordinarily from Burma, Indo-China, and Siam. The importation has been materially greater since 1900 than prior to that date.

The present place among Javan food crops is shown by the following table, showing areas in thousands of *bouws*: [1]

	1916.	1917.	1918.	1919.	1920.
Lowland Rice .	3724	3893	4058	4198	3952
Upland Rice .	550	560	555	640	644
Maize . . .	2230	2138	2167	2728	2762
Cassava . .	639	718	1052	1023	1140
Others . .	1036	1118	1362	1235	1207

A most interesting feature of this table is the area shown to be devoted to maize and cassava. Both are natives of America, capable of growing where rice will not, far less esteemed than rice, and regarded as little better than a recourse in necessity, but far easier to produce. Maize, though supposed to be of tropical or sub-tropical origin, has not yet been made to yield such crops in the tropics as are usual in the United States. But cassava yields more starch to the acre than any

[1] Dept. van Landbouw, etc., *Meded. van het Statistik Kantoor*, No. 4, Batavia, 1921, p. 15. The bouw is 1·73 acres, 0·71 ha.

other known plant, and is the most likely recourse to supplement rice wherever future increase of population makes an adequate rice supply impossible. At present Java has been forced farther in this direction than has any other land. Among the "other food crops" as listed above, another root crop, the sweet potato, is the most extensively planted.

An industry interesting here in its relation to rice growing is fish culture. One sees along the roads men with baskets, carried on the common Chinese shoulder poles, looking like ordinary pedlars; but their baskets contain countless spawn of gold-fish. These are planted in the paddies with the rice and grow there, or there or in other ponds without rice, and are harvested when the water is drawn off. The paddy thus raises two crops at once. As the native population is Moslem the hog is entirely absent, but the fish takes its place in more than one respect. Cattle are also very few. But the fish industry provides an ideally cheap and easy source of animal food, complementing, in a dietetic sense, the rice.

The absence of an adequate supply of live stock to cultivate the fields makes Javanese rice culture a hand operation to an extent not approached in the lands already discussed, and hardly equalled in Japan. This in turn makes a high *per capita* production impracticable, aside from the fact that other crops are raised on a large scale. The absence of draught animals results also in rather imperfect preparation of the soil. For, while general poverty has made sloth an almost impossible vice, the Javanese is not as strong in body as the Japanese, is not equally ambitious, and could not give his land ideal care with the means at his disposal if he were better endowed with muscle and zeal.

The practice is to transplant paddy rice, broadcasting being resorted to only for special reasons. The seed-beds are usually kept rather dry and not heavily fertilized, the belief being that the seedlings will stand transplanting better after such treatment; this is certainly true as to the dryness. As weeding is lighter work

than the preparation of the fields and does not use the total labour supply as completely as do cultivation and harvest, it can be better done. The Javan rice fields are clean to the point where they give the impression that weeding is hardly necessary, as if there remained in the country no source of weed seeds.

As stated in the preceding chapter, the Javanese practice is to harvest the heads one by one, of all methods the most careful of the rice and the least economical of human time. The contrast between the methods used in California and the Philippines, while directly the outgrowth of custom, has its economic basis in the difference in wages. The ratio of Javanese to Filipino wages is not very different from that of Filipino to Californian. The basic principle determining Javanese agricultural practice is that labour is very cheap, land is very scarce, and food is a necessity. The bunches of heads of rice are partly dried, then carefully stacked, and threshed by the primitive methods, after they are cured for a month. Rain does not hurt the rice in the stacks. It usually heats in the stack, and care is taken, if necessary, that it does not over-heat.

The Government has distinguished itself by its efforts to guard the grower against any crop failure as the result of his arduous efforts. It does this first by the provision of a reliable water supply.

> "The people have obtained very satisfactory results with the means at their disposal, and even at the present time about 55 per cent of the rice fields are watered by means of primitive canals constructed by them on the initiative of their chiefs." [1]

One of the most marked features of Javanese rice culture is the general practice of some sort of real irrigation, instead of depending upon rain or floods. The Government established a special service for irrigation in 1885, by the activity of which irrigation was by 1920 effective from permanent works on 584,000 ha., while works were then under construction to serve

[1] *Year-book of the Netherlands East-Indies*, 1920 (in English).

another 300,000 ha., and awaiting construction, or in the stage of planning, for still 471,000 ha. The effects of these works are to remove the greatest menace to rice culture—drought; to decrease the danger of damage by floods; to help in the control of pests; and in general to give a security to the industry which growers of other grains than rice never enjoy. In the judgement of the Government itself its greatest help to Javanese rice growers to-day, in the increase of average yields per unit of area, is provided by its irrigation systems. The increase of area in recent decades has likewise played a large part in providing more rice for the ever-growing population. In its attention to irrigation problems the service has made a careful study of the material brought by the water, in solution and in suspension, as well as of the provision of the water itself. Much of Java is so well and uniformly watered that rice can be produced at any time of the year. In the Preanger, for example, one sees fields being prepared, planted, in full vegetation, and being harvested, all at one time.

The study in Java of the means of overcoming the pests and diseases of rice was cited repeatedly in the chapter on that subject. Dammerman's admirable treatise on the borers might elsewhere have been allowed to suffice; but they have been assigned to van der Goot for still more complete investigation. And, as if the other insect pests were not already better known here than in most parts of the East, if not than in any other parts, the *Jaarboek*[1] says: "Bij dit onderzoek bleek opnieuw, hoe groote lacunes onze kennis van vele belangrijke rijstvijanden vertoont en hoe gewenscht een grondig onderzoek naar deze vijanden is"; and van Hewm has taken their study up anew. In contrast with the high figures given to describe the damage sometimes done by *mentek*, etc., it is surprising to read in the *Year-book* (1920) that the average damage by all causes is only 4 per cent.

In efforts to improve the hereditary quality and yield Java has led the world. Carolina rice was introduced

[1] *Jaarboek van het Dept. van Landbouw*, etc., 1919, p. 141.

and made a factor in the export crop more than half a century ago. The first hybridization, and the first extensive work in line selection, were performed here. It must be conceded that the results of these efforts in increased production per hectare have not been what it seemed reasonable to expect. As this lack of fulfilment of hope where such work has been most celebrated is a matter of general interest, it is in order to consider briefly the possible causes. As to hybridization, until the laws governing the segregation of characters and the enhancement of vigour by amphimixis and the expression these laws find in this particular plant are well understood, practical success is largely a matter of luck, even if the selection of parents and of hybrid individuals as parents of strains is performed with ideal care and skill. Burbank works with subjects which can be hybridized by the hundred-thousand; a small fraction of one *per mille* of valuable hybrid parents ensures the value of his work. Rice does not lend itself to hybridization on such a scale. If the proportion of success is the same the first really valuable rice hybrid may not happen yet to have been produced artificially. As to pure line selection, too much may have been expected of it. The same workers who were first to practise it in Java were, after a number of years, the first to question the efficacy of their methods. It is still too early, on the basis at least of published results, to form a positive conclusion as to the advantage of mixing a number of selected strains.

The Dutch labour under a difficulty of another kind in making their studies bear fruit in the field, a difficulty which, while felt, can hardly be appreciated without experience with its removal. This is the impossibility of intimate contact between zealous and skilful technical experts on one hand, and an apathetic and illiterate population on the other. With a probable disposition to glorify the work in which I was engaged, I cannot see that, up to 1917, when I left the Philippines, our technical work on rice there was the equivalent of that in Java

in any respect, except perhaps the testing of the native varieties, which is valuable only as a preparation for elimination and selection. But in the poorest year since that date the Philippine yield was better than it was in the best year before that date. Comparing averages for these last six years, 1917 to 1922, with the preceding six, themselves better than any which preceded them, the increase in yield per hectare was 44 per cent. This improvement has taken place with only insignificant Government assistance to irrigation. It has one explanation—education, operating in two ways: a growing literate population, infused from above with economic ambition, looking for and learning to welcome advice; and a native staff of technically trained experts.

In Java the highest instructional institution in the agricultural line is the Secondary Agricultural School in Buitenzorg. Its faculty and equipment are fine indeed, judged by Philippine standards. It needs only students to become an effective college; but there is no educational system which can prepare these properly in any considerable numbers. There is some complaint that its graduates are out of touch with practical agriculture, which is almost inevitable where any kind of collegiate education is a very rare distinction. Two "Cultuur" schools have been established at Soekaboemi and Malang. They teach agricultural science and practice to students with less preparation than is required at Buitenzorg, and prepare for appointment to minor positions in the Government service. And there were in 1920 fourteen village agricultural schools in Java and Madura and eight in the outlying islands. These are admirably adapted to the receiving capacity of students with a very limited previous schooling of any kind.

My own judgement would be that the greatest service of the Colonial Government to the native rice industry has been in the establishment and operation of its unique system of rural finance, consisting of what it calls "Popular Credit Institutions."[1] This

[1] *Year-book of the Netherlands East-Indies*, 1920, pp. 67 *et seq.*

system consists of credit and savings banks of three kinds:

1. The village rice credit banks (*desaloemboengs*).
2. The village money credit banks (*desabanken*).
3. The provincial, divisional, or district banks.

To avoid any risk of error in describing the work of the rice banks it is safest to quote:

The Village Rice Credit Banks.—These institutions, established by one or more communities, are owned by the native community, and were for the most part founded at the expense of the farmers. The Head of the Provincial Government draws up the regulations for the establishment and management. The contributions toward the founding come from members of the community in the form of *natura*, labour, and money. As soon as possible the contributions are returned from the profits made. For the most part this has already been done. In cases where the means of the inhabitants were insufficient, the Government, in exceptional cases, advanced free of interest loans of rice or even of money for the purchase of building materials.

The rice lent out by the banks is paid back *in natura* with an addition of 50 per cent by way of interest, which is reduced as soon as the debts contracted by the bank have been paid off, the stock of rice brought to its proper level, and a reserve fund formed. In most of the banks the rate of interest is already reduced. A part of the rice is sold each year, if necessary, to meet the expenses of administration from the proceeds; besides, by the sale of superfluous rice, after the debts are paid off, a reserve fund is formed which is invested in the popular or division bank. By this means the native community comes into possession of a building free from debt, with a stock of rice and a reserve fund in money, and the farming population may obtain, against a moderate interest, rice for its sustenance and for other needs.

The directors, who enjoy a part of the profits, consist of three farmers and the village chief, while for the book-keeping, as a rule, a competent person is appointed for several villages together, each of which he visits in turn.

The institution largely prevents the buying up of the harvest by dealers, with the consequent decrease of prices before and increase after the purchase, and keeps the price constant.

In one respect these combinations of warehouse and bank do more than this account claims for them. They provide the Government with information, more accu-

rate and reliable than would be possible otherwise, regarding the stocks and the need of rice throughout the island, thus letting it anticipate every shortage, even the most local, and make timely delivery from the place with rice to spare to that in need of it, without profit, between producer and consumer, to any middleman whatever, except to the banks themselves.

The village money banks are run on the same lines as the rice banks. They may exist side by side with the rice banks, and be helped in their foundation with rice-bank funds. As the communities strengthen financially, and transportation facilities improve and remove the necessity of storing much rice locally, there is a tendency for the money banks to replace the rice banks. The village banks have accounts with the district, divisional, or provincial banks. These, in turn, while legally autonomous corporations, are effectively agencies of the "Central Cash," founded in 1913 for the financing, supervision, and operation of this whole system of local banking.

The rice banks numbered 12,710 in 1911, and 10,385 in 1918. Their net capital increased from 146,618,240 kg. of rice and Fl. 588,000 in 1911 to 167,122,560 kg. of rice and Fl. 5,321,000 in 1918.

CHINA

The oldest reports of rice are Chinese, which fact has been construed by some as proof that the culture of rice originated there. The very simple true explanation is merely that history reaches farther back in China than elsewhere in the East. Neither in China nor in the neighbouring lands does it reach back to the beginning of rice culture, nor, probably, nearly to the beginning. Nor do the written or traditional records provide our oldest evidence; for language far antedates its use in literature, and *agriculture* in Chinese is *rice-culture*, as it is also in various languages. Before the dawn of history, then, rice must have been, as it remains to-day, China's staple crop. It is rice which underlies Chinese civilization,

the culture of rice which has made Chinese culture the most enduring on our planet. This culture is the whole basis, the warp and the woof at once, of the fabric of Chinese history. The passage of the dynasties, the succession of nomadic conquerors, the wealth and ease of one age and the hardships of another, the ups and downs of which history makes so much, even the learning gained and cherished as time passed—these are all incidents of this long history, embroidery on the more enduring fabric, rubbed off presently if they strained it, preserved if, as in ceremonial forms giving it a protection of sanctity, they made it stronger. Because they were rooted to the soil by their rice the Chinese have outbred and outlived their conquerors.

The standard practice of Chinese rice culture, and the unvarying ceremonies which rehearse this practice, and have helped to keep it uniform while every other human practice has changed and changed, we know. They are illustrated by the pictures [1] published by the order of K'ang Hsi as a model of the proper life. These illustrate agriculture and weaving. The series picturing the former are:

1. The immersion of the grain.
2. Ploughing.
3. Harrowing, with the heavy harrow, breaking the clods.
4. Harrowing with the comb (the *suyod* of the Philippines).
5. Harrowing with the light harrow, to smooth the ground.
6. Sowing.
7. Sprouting.
8. Manuring.
9. Lifting the seedlings.
10. Setting out the seedlings.
11. The first weeding.
12. The second weeding.
13. The third weeding.
14. Irrigation.
15. The harvest.
16. Grinding the grain.
17. Flailing.
18. Pounding with the pestle.
19. Sifting.
20. Winnowing.
21. Cleaning the rice.
22. Storing the rice.
23. The thanksgiving.

Except as to the general practice of its standard culture, we are in deep ignorance regarding rice in China.

[1] Perris, G., "Description of . . . Chinese Books," etc., *Internat. Rev. of Scient. and Prac. Agric.* 12. (1921), 1.

Certainly there are variants from the standard methods. Unirrigated rice is raised where irrigation is impracticable, and has been reported as common in Manchuria, farther north than irrigated rice. Austin states that upland rice in China dates from the tenth century; but he also says that it is cheaper to produce and yields more heavily than lowland, which surely is not the case. South-western China is a great museum of humanity; but these peoples seem to be more alike in the prevalence of transplanted and fertilized rice than in other respects.

China is famous as a land of unreliable statistics, or none. Such as have been published are too contradictory to be worth presenting here. Ignoring them it can be said that rice is the great crop of all Southern China, of the coastal region as far north as Kiang-Su, and beyond this where water is available. South of Honan in the interior, reports show only small districts where rice is not the staple. It seems safe to conclude that rice is the crop and the food of China, in not far from the same proportion as in India, that the area devoted to it is more likely to be greater in China than less, and that the product is materially greater. Travellers have given emphasis to the presence of other grains, and from their reports there has developed a disposition to doubt the old idea that China lives very largely by rice. Half a century ago Reclus estimated the population of India as composed of 75 million rice-eaters, 80 million wheat-eaters, and 100 millions living chiefly on millet, barley, and other grains. Fairly accurate statistics now show how rice outweighs the other Indian crops. And there is no valid reason to doubt that in China, where rice is a still more intimate feature of the more uniform national life, it is raised on a correspondingly large part of the cultivated land.

Even statistics of foreign trade, the most reliable of figures elsewhere, are not reliably kept for Chinese rice. There is a considerable annual importation, more than 500,000 tons in some years, but probably not in all. This comes from the south, either transhipped at

Hong-Kong, or directly from Saigon and Bangkok. The export of rice has been forbidden for centuries. But China is wherever Chinamen live, and colonies of Chinese in foreign lands may secure their favourite home rice unhindered by this prohibition.

Chinese rice culture, unchanged since all human industry was performed with hands and hand tools, remains so still. In so great a land there are naturally some differences in detail, as some districts are almost without draught animals, while others have and use them. The plough is much more used than in Japan. As the great areas of intensive rice culture are flat, water must be lifted to the fields. This is accomplished in a variety of ways, the labourers themselves being the commonest source of power. Weeding is repeated and perfect, but not exceedingly arduous, because the weeds are always well in check. Harvesting and subsequent operations are all performed by the ancient methods. Much glutinous rice is grown, the estimates (probably too high) running to above 20 per cent. Without at all disturbing the place of white rice as a staple, red rice is also grown. It may be glutinous or may not, and, on a relatively small scale, sells at an advanced price.

The outstanding feature of Chinese rice culture is the use of fertilizers.[1] All offal, of man and beast, from city and country, is collected, stored without waste by leakage or much by evaporation, allowed to ferment and decay, and applied, liquid, to the land in small quantities so that none may be lost, and timed to the needs of the rice. It is applied intensively to the seed-beds, and to the fields as a whole in the remaining measure of the supply. What garbage there is is similarly rotted and used, with all other available organic matter. The sluggish streams and the canals are dredged and the ooze is carried to the fields. Only this incessant and meticulous care, to let the soil deteriorate in no single year, can have made it possible to raise rice "forever," sometimes in the south two crops to the year without

[1] King, F. H., *Farmers of Forty Centuries*, Madison, 1911.

interruption. King's supposition that there are fields where this has gone on steadily for four thousand years is reasonable.

Without statistics, it may be accepted as sure that average yields are higher in China than in any other Oriental land except Japan. They will be increased, as they have been in Japan, where the older practices were like the Chinese. But there is no ground for doubt that Chinese consumption will keep pace with any increase in the production, as the Japanese consumption has more than done.

JAPAN

Japan is the Land of Bounteous Rice Crops. Said to have been so called in ancient times, it is indeed so now. More than half of the cultivated area is in rice—2,880,000 (7,200,000 acres) out of 5,660,000 *cho*, in 1912.[1] These figures include the whole of Hokkaido, but little rice is grown there, and none beyond 44° of latitude. All available land has been in rice for centuries; but increasing density of population and rising prices have caused more land to be available, so that there has been a slow increase in the area. The acreage was 6,100,000 in 1878, and 7,661,100 in 1920. The yield per acre was always greater than in any other Eastern land, except perhaps China, and has increased remarkably. The crop totalled 3,971,381 tons (25,282,540 *koku*—official statistics and probably too low) in 1878, and 9,928,700 tons (63,183,000 *koku*) in 1920. The latter figure is probably quite correct, and represents an average yield of 2591 lb. of cleaned rice per acre, which is almost that of Spain, and well above that of any other land.

The population of Japan is about sixty millions. With the rapid increase in recent years, the trend toward industrialization in cities has been very strong. The nation has increased in wealth faster than in population,

[1] Yokoi, T., "Agricultural Economy of Japan," *Monthly Bull. Agric. Intel and Plant Diseases*, 4. (1913), 331.

and has accordingly been able to increase the *per capita* consumption of rice. Increase in population, increase in *per capita* consumption, and drift into the cities have combined to make the total consumption outgrow even the remarkable increase in production. A very considerable exporter of rice during the most of the period since it opened its ports to commerce, Japan now produces only about 92 per cent of the rice its people eat. For a considerable time fine rice was exported at high prices, while cheaper rice was imported, chiefly from Saigon. But even this export has now effectively ceased. In 1920, the year of maximum crop, the value of the export was only $2,942,403, of which $2,456,228 was for export to Hawaii, purely to meet the demand of the large Japanese population there; and the insignificant remainder may well have served the same purpose elsewhere.

Japan has endeavoured to meet its need for rice by annexing territory, but the best efforts in Formosa have produced only eight or ten thousand tons a year above the local consumption. The exploitation of Korea is more successful, and rice of Japanese varieties raised there now contributes about 5 per cent to the Japanese supply. This leaves about 3 per cent as an average, fluctuating with the annual crops but assuming good ones, to be imported. According to the prosperity of the time, this 3 per cent or more is cheap rice from Saigon, or rice of preferred Japanese type, from California.

It is true, as a Japanese writer remarks, that the visitor to country Japan is struck first by the smallness of the plots of land and the steepness of the terraced hill-sides. But Japan is in these respects not different from the lands which have just been discussed. Japan is far from as densely populated as Java, has more and much greater cities, and is still materially short of going as far in the utilization of every possible acre. Neither is it probable that Japan's soil is naturally less fertile, for the supposed abounding fertility of tropical soils is

not a reality. But Japan is as a whole a ruggedly mountainous land, and its hill-sides have been terraced and brought into service to an extent rivalled in few places in Europe and nowhere in America; to an extent incompatible with such use of live stock in cultivation as is typical of European farming.

While Yokoi refers to Japanese agriculture as "spade farming," hoe farming would describe it more graphically, for the implement in universal use is mounted like a hoe. In describing Japanese farming tools, Uyeno [1] says:

> Of these tools the hoe, or *kuwa* rather, is by far the most important. It is used in a variety of ways, and with a skill surprising to one accustomed only to the simple uses of the hoe in Occidental hands. It is used for digging up the soil, thus taking the place of the spade, which is little used. With the *kuwa* also the soil is pulverized and levelled, the tool thus accomplishing on a small scale the work of the plough, the harrow, and the roller.

This *kuwa* has typically a blade like a spade, 4 to 8 inches broad and 10 to 20 inches long, set at an acute angle, 30° to 85°, to the necessarily heavy handle. The larger sizes have wooden blades, shod with iron; old accounts describe it as having shell where iron is now used for the edge.

> It is said that there are as many as a thousand different kinds which have been worked out to meet the demands of the various conditions of the soil and the different purposes of use. When wet or heavy soil is to be worked, the blade of the *kuwa* is divided into two, three, or four prongs, like that of a garden fork.

Ploughs are much less extensively used, both because of the scarcity of draught animals and because of the smallness of the paddies. They are small, one-animal implements, which stir and shift the soil rather than really turn a furrow.

[1] Uyeno, H., "The Use of Agricultural Implements in Japan," *Monthly Bull. of Agric. Intel.* etc., 4. (1913), 689.

In weeding rice fields, an implement somewhat like the Norwegian harrow is used. Teeth are set in straight or curved lines in a wooden revolving cylinder and the implement is drawn by hand. In addition to the above-mentioned implement, there are various other tools used in weeding.

Lowland rice is always transplanted; upland is sown broadcast or drilled in with hand-drills. In transplanting, the hills, of six to ten seedlings, are set ten to twelve inches apart, in rows a foot apart, on good ground. This wide spacing permits cultivation, and does not interfere with the yield. In the use of fertilizers, the Japanese follow the Chinese precepts, introduced unknown centuries ago, fertilizing being done between irrigations as well as in advance. To these practices, however, they have added scientifically guided use of green manures. The most favoured of these are the soy bean, itself an important crop, and *Astragalus sinensis*, *genge*. The soy bean oil-cake is also used; and there is some use of the common commercial fertilizers, phosphates being the most efficient, on the whole. *Genge* constitutes about 71 per cent of all green manures used.[1] Its excessive use on some soils interferes with the proper nutrition of the rice, by the formation of organic acids and their salts, and perhaps also by the evolution of reducing gases.

When Japan was adopting what it wanted of Western culture, it turned to Germany for scientific agriculture, and brought in, as dean of the college of agriculture of the Imperial University, O. Loew, one of the foremost men of his time in the recognition of scientific plant industry as applied botany. The result was that the study of rice was devoted to really basic principles, and that until the last few years what knowledge we had of the particular physiology of the rice plant was the result of Japanese work. Thus the concept of balanced provision of the chemical elements of plant food, in which

[1] Onodera, I., " Über die Gase welche im Reisfelde bei der Zersetzung von *Genge* (*Astragalus sinensis*) entstehen," *Ber. Ohara Inst. f. landw. Forsch.* 1. (1920), 556.

antagonism as well as nutrition plays a part, and in which elements, not themselves deemed essential as food, may play an important part, was applied to the study of rice fertilizers in Japan before it was applied to the study of any crops in most countries.

A series of early papers by Aso showed that the utility of liming the soil depended upon its magnesium content, an excess of magnesium demanding the addition of lime. Miyake,[1] a decade later, showed that salts of the alkali metals—Na_2SO_4, $MgSO_4$, $NaNO_3$, $NaCl$, $MgCl_2$, KCl, KNO_3, etc.—used separately in 0·1 normal concentration, are "very poisonous," but that the toxicity disappears in proper mixtures of the same total concentration. Calcium is the most effective in antidoting the toxicity of other bases. Potassium and sodium offset ("antagonize") each other. Proper 3-salt mixtures are better than 2-salt. Alkali soils are widely distributed in central and southern Formosa, according to a publication in Japanese by Oshima and Shibuya.

Nagaoka[2] showed that rice soils tend to become acid because the imperfect aeration makes oxidation stop with the formation of organic acids. If this acidity effects their solution, otherwise insoluble phosphates work very well. The fact that nitrates are not a suitable form of nitrogenous fertilizer for paddy rice was first proved in Japan.[3] "It was sufficiently proved in all of the preceding trials, that paddy plants cannot utilize nitric nitrogen as well as ammoniacal nitrogen." *Juncus* and *Sagittaria*, natives of wet places and sometimes weeds of irrigated rice, are like rice in this respect. The early beginning of this work in Japan is shown by Knapp's statement[4] in 1899:

[1] Miyake, K., "Influence of the Salts common in Alkali Soils upon the Growth of Rice Plants," *Journ. Coll. Agric. Tohoku Imp. Univ.* Sapporo, 5. (1914), 241-319.

[2] Nagaoka, M., "On the Action of various Insoluble Phosphates upon Rice Plants," *Bull. Coll. Agric. Tokyo,* 6. (1904), 215.

[3] Nagaoka, M., "On the Behaviour of the Rice Plant to Nitrates and Ammonium Salts," *ibid.* 6. (1904), 285-334.

[4] Knapp, S. A., "The Present Status of Rice Culture in the United States," U.S.D.A., Div. of Botany, *Bull.* No. 22, 1899.

At the Imperial College of Agriculture at Tokyo, Japan, a series of experiments has been conducted on the same plats for nine years to determine the elements best suited to increase the yield of rice in Japanese soils.

Complete fertilizers were found to produce the greatest crops, and phosphorus to be the most generally needed element.

Another quotation from Knapp [1] gives old but permanently valid conclusions in another field:

Some deductions which the Japanese experimenters have made may be profitably noted here: (1) The great importance of selecting pure-bred seed of even quality and size of grain. (2) The removal of any light or imperfect grains. This is done in Japan by soaking the seed rice in water several days till it is about ready to sprout, when it is thrown into salt water of 1·3 specific gravity and allowed to remain two minutes, being gently stirred meanwhile. The light grains will float; the others are removed, washed in cold water, and planted. When a seed drill is to be used the damp seed is first dried by being rolled in the ashes of rice straw. (3) Even sprouting of the grains is very essential to even ripening of the crop. This is accomplished by previously soaking the seed as above stated.

Japanese studies of germination have been cited in Chapter I., as have those of diseases and pests in Chapter III.

Suggestions from abroad as to the improvement of rice culture in Japan would be likely to prove outlandish in another sense. The following suggestions, however, on Japanese authority, are worth presenting, especially as some of them apply to other Oriental lands with considerably greater force. The quotations are again from Uyeno:

1. For cultivation, the use of farm animals should be increased.
2. The advance in the co-operative system for threshing should make it possible to use animals and mechanical powers in this work.
3. The use of ploughs and harrows constructed to suit the needs should be encouraged.

[1] Knapp, S. A., "Recent Foreign Explorations, etc.," U.S.D.A., Bureau of Plant Industry, *Bull.* No. 35, 1903.

4. In the case of wet fields, special implements must be invented, since necessity has not called for the invention of such devices in other lands.

5. The drills and dropping machines now in use should be improved.

6. For harvesting there seems to be no possibility of using Western machinery, and the sickle should be so modified as to be made more effective.

7. In the preparation of grain, however, it is most desirable that Western threshing machines should be brought into use.

Many of the implements of the Occident are adapted for use on large farms only, and none have yet been invented suited for use in the wet ground of the rice fields. We must look for adaptation of imported implements, and improvement of existing domestic types, to bring into being the devices called for by the new conditions in New Japan.

The straightening out of the old irregular boundaries between the fields and the re-allotment of the land which is now in progress throughout the country will pave the way for the use of machinery drawn by animals or other motive power.

Knapp illustrates, with before-and-after maps, the rediking of a plot of 25 acres, which made 138 regular paddies where there were previously 409 irregular ones. It is noted that even after the operation the average size was less than one-fifth of an acre. It may be that except for the loss of land due to the exceedingly numerous dikes, Japanese yields per acre would show themselves above those of Spain.

It is altogether improbable that any future increase in the home Japanese production, unless in single exceptional years, will keep pace with the increase in consumption. The Government, however, anticipates much greater yields than have yet been attained. Its first estimate of the 1922 crop was 70,000,000 *koku*,[1] which would have made any importation unnecessary; but the harvested crop was only 60,700,000 *koku*. On the other hand, it is not improbable that efforts to increase the production in Korea and Formosa will bring the production of the Japanese Empire to practical equality with the consumption.

[1] Rice-growers' Association of Calif., 1923 *Year-book*.

OTHER ASIATIC COUNTRIES

Rice is raised in Turkestan and Transcaucasia, the reported area in 1914 being 636,000 acres, not including Bokhara and Khiva. The yields apparently average little more than five hundred pounds of clean rice, though reports conflict. There is linguistic evidence that rice was grown in upper Asia before the Aryan dispersal.

What is now Iraq produced less than 50,000 tons in good years before the war, and exported a fraction of this. While, with ample water when it is used, lower Mesopotamia at least should be a good rice country, there is no record of its culture in ancient Sumeria or Chaldea.

Persia produces some rice wherever water is available, which is chiefly in the flat country at the south end of the Caspian Sea. Some rice is imported from India, but much more is exported, in normal times chiefly to Russia. The principal rice-growing province is Gilan, supposed to produce annually nearly 200,000 tons—whether rice or paddy is not clear. Persia is most famous, in connection with rice, for the fancy food concoctions of which it forms the basis.

AFRICA

There is no report of rice in Egypt in ancient times nor in the age of the Caliphs, but it has been grown there as a minor crop for an unknown period. It is almost confined to the delta region, and is the staple crop about Rosetta. The area fluctuates greatly from year to year, but rarely exceeds 300,000 acres. In yield per acre, Egypt has been supposed to rank about with Japan. But this would be hard to believe of a land where rice is not transplanted, nor generally fertilized except by the Nile, and recent statistics are very different. In 1920, for example, the yield from 164,900 acres was 732,050,000 lb., or 2301 lb. of rough rice to the acre. A report on an experiment with transplanted

rice[1] shows a lower yield from the transplanted plot than from the broadcasted check plot; but the figures on the latter, if I can interpret them, are exceptionally high.

The reason given for not generally applying manure is that it would be removed by the water before the plants could get it.[2] It is used near Rosetta. Cartwright applied barnyard manure, at the rate of 7·5 cubic metres to the *feddan* (just over an acre), to a plot with the drains left open, so as to permit free leaching if it would occur, and increased the crop thereby from 11·75 cwt. to 18·75 cwt., presumably of paddy rice. On another plot with the drains closed, the increase was from 25 cwt. to 34·75 cwt., the net profit in each case being more than three times the cost of the manure. In a later experiment the same author[3] increased the crop by 18 per cent by applying 85 kg. of sodium nitrate to 3 *feddans* and 8 *qirats* of land, paying a direct net profit. He reports *Panicum Crus-Galli* and *Andropogon annulatus* as the worst weeds in Egypt.

Throughout tropical Africa some rice is raised where there is water, but it is nowhere raised on a large scale, and is nowhere an article of commerce. In this region a number of varieties or species very similar to cultivated rice seem to be native. The most remarkable of these is the perennial rice, mentioned in Chapter I. Even as far south as Natal rice is grown on a small scale, and attempts have been made to extend the cultivation. Wherever in South Africa there is a considerable Oriental labouring population heavy importation of rice results, so that locally grown rice would have a good home market.

Rice has always been the staple food and crop of the Malayan natives of Madagascar, and Carolina rice is supposed to have originated there. In 1908 the area

[1] Dudgeon, G. C., "Experiment with the Transplantation of Rice on the Indian System," *Agric. Journ. Egypt*, 4. (1914), 71.
[2] Cartwright, W., "Preliminary Note on the Manuring of Rice," *Agric. Journ. Egypt*, 8. (1918), 39.
[3] *Ibid.* 9. (1919), 125.

was 875,000 acres and the yield about 440,000 tons of clean rice. This left a small margin for export, as has also occurred during the subsequent years.

LATIN AMERICA

Brazil and British Guiana are the only countries of South America which produce more rice than they consume. Rice was first introduced into Guiana by the Dutch more than two centuries ago, from Carolina, but has become an important crop only recently, and as a result of the importation of East Indian coolies. It is now the chief food crop and ranks next to sugar among all crops. The average area from 1915 to 1919 was 57,500 acres, and the average yield 140,820,000 lb. of paddy, an average of 2449 lb. per acre. There is a small annual surplus for export, which is expected to increase. Previous to milling, the paddy is steamed, as already described in treating of the Malay States. The Government has helped the industry chiefly by importing and testing varieties, and distributing considerable quantities of seed.

Rice has been grown to some extent and consumed on a large scale in Brazil for a very long time. As an industry of importance, it is confined to the southern states of the Republic, the order of importance being Rio Grande do Sul, São Paulo, and Minas Geraes.[1] In this region it dwindled during the great expansion of coffee-growing, but has come to the front again during the past two decades. Imports were about 100,000 tons in 1902, 7777 metric tons in 1913, and 7 tons in 1921. The exports during the past four years have been :

1919	28,423	metric tons.
1920	134,554	,, ,,
1921	56,605	,, ,,
1922	37,865	,, ,,

[1] This and other information on Brazil is supplied by Mr. A. Gaulin, American Consul-General at Rio de Janeiro.

Argentina and Uruguay usually take about 80 per cent of the export, although in 1920 Germany was the biggest buyer. The total of the 1919–20 crop was about 500,000 metric tons.

Except in Rio Grande do Sul, the methods are described as primitive. In that state they appear since 1905 to have been similar to those used in North America. There is a considerable importation of modern implements and machinery for this work. The usual method of seeding is broadcast, and transplanting is not done. Pests are a serious menace to the growing rice, but it is not stated what these are.

At Iguape, São Paulo, there is a thriving colony of Japanese rice-growers. There is good reason, which I have from other sources than Rio de Janeiro, for anticipating a very material growth of the Brazilian rice industry as a result of the participation of these industrious and skilful cultivators.

Next among South American countries, in the order of importance, is Peru. The average annual crop from 1915 to 1919 was 126,760,000 lb. of paddy. It is raised near the coast, where, because of the scarcity of water and its value for other crops, it is unlikely that the production can reach and maintain the level of the domestic demand.

Argentina has been a steady importer of large quantities of rice from the lands whence her people came, Spain and Italy, and recently from Brazil. There have been repeated attempts to establish a local rice industry.[1] These have fallen short of success for various reasons—weeds, pests, lack of good milling facilities, etc.—but, underlying most of the difficulties in detail, chiefly because of the lack of sufficient study and understanding of the local problems, and of adequate population and support. To remedy the first of these general difficulties, a Japanese expert was employed by the Government. The efforts have been widely scattered;

[1] Gache, A. J., "La culture du riz dans la République Argentine," *Actes du Congrès Internat. du Riziculture,* Valencia, 1914, p. 242.

and Argentina is a country great enough to provide a wide range of conditions suitable for rice, but requiring a corresponding range of adaptation of practice. Thus, in San Juan, Japanese varieties have given the best results; but in Tucuman these were unproductive, as compared with European varieties, *Ranghino* in one place and *Creole* in another. There seems to be some recent expansion, for the area reported in 1922 is 29,500 acres, or more than in any preceding year; but as long ago as 1908 it is said to have been 20,000 acres.

The history of rice in Uruguay [1] is likewise a chronicle of failures. These are charged "aux échecs subis par suite de l'ignorance des procédés de culture de cette céréale, et peut-être aussi à des difficultés d'autre genre et que nous ignorons." Variety tests indicate that late or tropical varieties will not mature.

However unfortunate most attempts to raise rice in the great valley of the Plata have been, it remains practically certain that no part of the world offers a more inviting opportunity for the development of a rice industry of the distinctly American type, providing a great surplus above the needs of the population engaged in it. With somewhat less confidence, a similar declaration may apply to the savannas of the Orinoco. The forested valley of the Amazon offers no such promise. This is not primarily because of the expense of clearing; the temporary great fertility of cleared forest land might offset this cost. But the climatic conditions which keep a region naturally treeless are those which permit the use of the machinery which, in turn, enables a sparse population to keep great fields in cultivation. The climate which produces the tropical jungle makes tractors of doubtful utility and binders useless. Only a very dense agricultural population can replace the jungle with rice.

Venezuela is another country importing considerable rice, and producing an insignificant amount. As in

[1] Kessissoglon, T., "La culture du riz dans l'Uruguay," *Actes du Congrès, etc.*, 1914, p. 235.

Argentina, the attempts to establish it as a crop have been thwarted by the difficulties which usually make path-breaking efforts unprofitable. Even though the cultural methods applied to rice in a new land are such as can survive unchanged while a prosperous industry develops and operates, these first attempts are very likely to be highly unprofitable in themselves. It may be presumed that, unlike many new crops, rice will find a ready market. But it will not find ready and good milling facilities. It cannot reckon with a supply of labour skilled in the industry. Pests which are only incidentally enemies of rice may destroy small plantings, but do minor harm to it as a staple crop; birds and a small yellow beetle so attack rice in Venezuela. And the financial insecurity of a new venture may result in failure where only confidence is required to bring success. And only luck or understanding can make the first attempts use the most appropriate methods.

Venezuela has natural advantages for rice production by Oriental methods, and is one of the most inviting regions in the Tropics for experiment as to the feasibility of the North American methods. But private enterprise (unless well subsidized) will hardly undertake these experiments with sufficient resources and patience to be likely to carry them to a successful issue. And it will require a Government, more able to promote the future economic development than Venezuela has enjoyed in a long time, properly to conduct them itself.

According to a brief report by Ezpeleta to the Valencia Rice Congress (*Actes*, p. 363), the seed used on the small present plantings is called *Creole,* and is supposed to be of Italian or Spanish origin. Tests of *Carolina* gave too poor a yield to be continued.

Mexico and the Central American republics all produce rice on a small scale, and import more than they produce. Imitation of Spanish methods in any of these lands should make the industry profitable; and the inherited Spanish culture should make such imitation easy.

SPAIN

Spain is the second country in Europe in rice production, and the first in the world in yields per acre. According to the International Institute of Agriculture, areas and yields in recent years have been :

Average.	Area in 1000 Acres.	Yield of Paddy in 1000 cwt. of 100 lb.	Average lb. per Acre.	
			Paddy.	Rice.
1915–19	105·6	3396·6	..	..
1920	119·8	6378·9	5325	3328
1921	113·4	5766·7	5085	3178

The yield of rice per acre is calculated as five-eighths of the weight of paddy. An extract from official Spanish reports, made for me by the kindness of Mr. Pendergast of the United States Department of Commerce, shows slightly, but not materially, smaller yields for the last two years. As an industry of importance, Spanish rice culture is confined to Valencia and Tarragona, the relative importance being about as 3 to 1, but Tarragona being a little the higher in yields per acre.

The current story is that rice culture was introduced to Spain by the Moors, which may be true, but probably has no historical connection with the present industry. It is sometimes added that this was Europe's first acquaintance with rice. The latter statement may be checked against modern Greek accounts of marvellous yields in ancient Thessaly ; and then both can be discarded as certainly incorrect. Rice in modern Spain became important later than in Italy, and has borrowed much from that country. The likeliest source of its most distinctive feature, transplanting, is Manila.

It might seem called for, in view of the unique accomplishment of Spain in securing high yields, to

describe Spanish methods in particular detail. But the explanation of Spanish success is not to be found in peculiar single methods, but in the combination of methods, individually familiar elsewhere, and already described. According to the *Indian Trade Enquiry Reports on Rice* (p. 105):

> The chief characteristics of the Spanish methods of cultivation are (1) the universally accepted importance of a thorough cold weather cultivation of the fields, made possible by the use of specially adapted implements; (2) the necessity of employing considerable quantities of suitable nitrogenous and phosphatic manures; and (3) the value of introducing exotic varieties (notably Japanese) with a view to checking deterioration of rices cultivated too long in the same locality.

To these should be added a fourth characteristic, more important than any of the three given—the invariable practice of transplanting.

The Spaniards are thoroughly confirmed in this practice. In pointing out that one of its merits is protection against the attacks of snails, destructive in Portugal, Carvallo[1] said:

> It has been demonstrated, and is most evident, that rice ought not in most cases to be broadcasted, and the Portuguese rice-growers will come to the adoption of transplanting, as it is practised in our region; then they will see that there is no other way, and will do so promptly, and will be astonished that they were ever able to employ any other method.

The primary importance of transplanting was witnessed at once by Professor Tognato of Novara, who remarked on other factors—climate, soil, water, and the use of fertilizers—as incidental, and added:

> Mais j'entends que cette pratique peut exercer une influence notable sur la production et je pense, ou mieux dit, j'espère que nous aurons tout avantage à essayer cette opération en Italie.

And in fact, since the Valencia Congress, attended by the Italian experts and by many Italian rice-growers,

[1] *Actes du Congrès Internat. de Riziculture*, Valencia, 1914, p. 320. This volume, [illegible], gives an excellent account of Spanish rice culture and much information regarding that in Italy.

there has been a marked increase in the use of this method in Italy also.

After transplanting, which was part of the industry from its beginning, the next feature of Spanish rice culture to be highly developed was the use of fertilizers. In choice, amount, and manner of application the Spanish are masters of the use of commercial fertilizers. They use ammonium sulphate, in particular, in quantities which have been found injurious instead of merely unprofitable in some lands. The good results obtained in Spain are very likely correlated with the suitable use of water.

It is not clear what the authors of the *Indian Trade Enquiry Reports* had in mind as cold weather cultivation. The Spanish paddies are usually, in most places, covered by shallow water during the fore part of the winter. *Leersia oryzoides*, L., a marsh grass, is one of the worst enemies of rice in Spain. The campaign against it is made while the water is on the ground, by the use of modified disk harrows or by slightly modified Acme weeders, implements which cut the weeds well below the surface of the ground, and at the same time mellow and even the soil itself.

Just as soon as the ground dries, which may be in January, or may not be until March, the ploughing is done. An excellent illustrated report to the Valencia Congress, by Guardiola (pp. 186 *et seq.*), states that it is only within thirty years that the primitive Roman plough went out of use in Valencia. Since that time the preferred implements are mould-board ploughs, of a size and shape to turn a furrow and at the same time leave the soil as open as possible for the sake of aeration. Because the re-working of the soil preceding transplanting gets rid of any weeds which grow after the ploughing, and because ploughing with the available means requires much time, it is begun as early as the weather permits. One may not conclude, because January ploughing is beneficial in Spain, that it would be good practice elsewhere—in California, for example. The Spanish fields are

often of one hectare, not often of more than two hectares. Their smallness prohibits the use of the huge tractors and gang-ploughs with which, in California, ranches of hundreds or thousands of acres are ploughed, harrowed, and dragged, so immediately before the seeding that weeds have no time to get a head start, even if it be wet enough for them to germinate.

The growth of the rice industry, with its demand for the rapid cultivation of very heavy soils, has brought about an interesting change in the equine population of Valencia. The native Andalusian breed was too light, and has been replaced by a very stocky imported strain, the *breton*, and by crosses between this and the native variety. Janini has a splendidly illustrated report on this subject in the *Proceedings of the Valencia Congress*, pp. 261 *et seq.*

As to varieties, the chief direct source has been Italy. The favourite, as to quality and therefore market-price, is *bomba*. For high yield, *amonquili* and *Benlloch*, which is the *Chinese originario* of Italy, are most esteemed, the former, however, being very subject to damage by *falla*, and the latter tending to become so. Some Japanese importations are heavy yielders, and relatively immune to attack. The exchange of seed between Italy and Spain is very free, and a variety found good in one land is likely to become popular in the other without delay.

Effectively, but one disease is recognized, because whatever ails the rice is called *falla*. As Carvallo said (p. 321):

> Toute circonstance qui influe défavorablement sur la végétation ; toute autre quelconque qui nuise à la fécondation de la fleur, ou entrave le processus de l'amidon pour la formation du grain, sera cause déterminante d'une faille plus ou moins importante.

ITALY

As long as Europe has had a rice-growing industry, Italy has been its principal seat. Recent statistics on Italian areas and yields are :

Average.	Area in 1000 Acres.	Yield of Paddy in 100,000 lb.	Average lb. per Acre.	
			Paddy.	Rice.
1915–19	343·4	11,541·2	..	..
1920	276·5	9,947·3	3598	2248
1921	286·6	10,361·8	3615	2258

As a most authoritative statement, covering several phases of Italian rice culture, I will quote at length remarks delivered by Professor Novelli, the eminent director of the Vercelli experiment station for rice culture, in the course of the discussion of fertilizers at the Valencia Congress:

It is well to note in advance, in order that one may better understand the points I am going to make, that the larger part of the culture of rice in Italy is performed in alternation with other cultures, a system which, among other advantages, presents that of periodically improving the physico-chemical conditions of the soil, conditions which suffer much during the period of muddiness, which makes it necessary to increase the fertility of the soil.

The order of succession of the crops is diverse and variable, but we can regard as a typical alternation, generally followed, that which consists of rice in the first, second, and third years; wheat or oats in the fourth, with forage intersown with the cereal in the spring; fifth and sixth, forage, which ordinarily is common clover.

Another sequence, also very common in the rice-growing regions of Italy, for example at Mantua and Bologna, where the lands are strong and very clayey, is as follows: first year, rice; second and third, cereals (wheat, oats, maize); fourth, meadow clover or alfalfa.

Among the fertilizers we have in the last years seen a multiplication of the phosphates, the extraordinary efficiency of which is generally recognized, as well because they augment the yield as because they render the rice more resistant to diverse diseases, among these, to *brussone*.

It can be stated that there does not exist in Italy any rice

field, be it of the first, second, or third year, which is not fertilized with 4 to 6 quintals of phosphatic fertilizer per hectare.

As phosphatic fertilizer, the mineral superphosphates and Thomas-slag have been adopted generally for the more clayey soils; and sometimes, for the less fertile lands, the bone superphosphates.

These fertilizers are scattered, in general, a little before the land is worked in preparation for the seed. On the most clayey soils there is also, in advance of seeding, a manuring with plants buried green, plants sown in the autumn, so as to favour their development, and thus indirectly that of the rice.

As to nitrogenous fertilizers, they are applied on a great scale, for nitrogen is highly necessary to rice; we strive to make this fertilizer as abundant as possible by means of organic matter, especially by ploughing legumes under green.

During the first year of rice (because, as we have said, the rice follows clover in the succession) we usually apply no nitrogenous manure, because the land is already of itself sufficiently rich in organic matter, coming from the decomposition of the leguminous herbage which we work in before sowing the rice.

From the second year on, when the land is kept in rice for several years, then immediately after the first or the second year, we sow plants to be ploughed under; we sow these in autumn at the moment of withdrawing the water and drying the land for the rice harvest. The seed, sown while the land is still covered with shallow water, or at least soaked, germinates promptly; and under favourable conditions of moisture and temperature it has already made some growth when the rice is cut. When the rice has been removed the superphosphates are applied, which permits the rice [1] to take root before winter and oppose the necessary resistance to the frosts of that season. In the spring, as soon as the temperature is favourable, the growth of the rice [1] is such that by the end of April, when the proper time comes for the sowing of the rice, there is already an abundance of organic matter to be ploughed in.

Generally, one sows a legume (having regard for their power to fix the nitrogen of the air) so that when buried it may provide nitrogen to the soil. The legume which, because of its period of vegetation, suits our climate the best is the crimson clover, but one may employ other legumes, such as the beans, vetches, etc.

This burying of organic matter certainly is one of the best means of nitrogenous fertilization, as well because of its economy,

[1] Evidently misprints; it ought to read *the legumes.*

as because, aside from the accumulation in the soil of useful elements, it improves notably the physico-mechanical properties, and because, in the slow decomposition of the buried matter, it yields up slowly its content of nitrogen; thus one obtains a sort of regulated vegetation, which renders the rice less susceptible to being attacked and injured by diverse diseases.

I must diverge here to explain how it is that in our Italian rice lands we can produce also a considerable quantity of manure; this is because, as already stated, rice is grown as one of a succession of crops. It occupies therefore only a part of each land-holding, the remainder being devoted to other cultures, among which clover dominates, which permits us to maintain numerous enough animals, both beasts of burden and milch stock; so that, in our exploitation of rice, while we attain the utmost intensity of rice production, we also achieve great intensity in animal husbandry; and it is this which places at our disposal on the farm a good quantity of manure, applicable to the rice or to other crops.

Theorists have sometimes affirmed in times past that manure was a necessary evil, that it was in no respect good for rice, being at once an efficient propagator of weeds, and of almost no utility, considering the demands of rice for the chemical elements. Many years ago I desired to study this question, and to-day I am convinced, as are all rice-growers, that in practice manure is of great importance in the fertilization of rice fields, much greater than its low content of chemical elements will explain.

After the land has been submerged a year in the culture of rice, it is evident that it has become poor in air; the transformation of much of the organic matter contained in the soil is hindered as a result of the prolonged submergence; in this case, the manure, even distributed in small quantities, modifies the soil physically, makes it more spongy and better aerated; it contributes, moreover, by its fermentative activity, by its bacterial flora, organisms which diffuse and nitrify the organic matter of the soil, and which are extremely useful because they help to initiate and intensify the transformation of the excess of organic matter which accumulates in the soil as a result of submersion, and which would otherwise become useless, be lost, and might even injure the rice.

The nitrogenous fertilizers are applied, then, to the rice of the second and third years, as well as to permanent rice, by manure, according to the quantity made available by the system of management, if that suffices; or by ploughing under green manures, where they are sown for that purpose; and we finish finally with other nitrogenous organic fertilizers, such as the

horns and hoofs of animals, and especially with ammonium sulphate, in the amount of 1 or 2 quintals per hectare. Quite recently, cyanamide of lime has been introduced among the nitrogenous fertilizers, and has given excellent results, particularly in old rice fields and on land constantly in rice.

It is evident that if manure or green manures are wanting, it is necessary to augment in proportion the application of the nitrogenous fertilizers just mentioned, sufficiently to satisfy the needs of the rice.

In recent years we have also begun the introduction of potassic fertilizers, as a result of the judgement which assigns to potash one of the most important places in the chemical constitution of rice. We have made numerous experiments on this subject, which have always given good results, although not always very appreciable, especially when they were performed on very clayey soils, and sometimes on those already rich in potash; but, in spite of the favourable results we have generally obtained in these trials, potash fertilizers have not gained any great following.

In all respects the result of numerous experiments confirms the utility of potash fertilizers; if many rice-growers are not convinced, this must be attributed to the fact that the effect of the potash is hardly manifested during the vegetative development of the rice, the plant itself not seeming any finer or more vigorous; but, as we have already remarked, the effect of the potash makes itself felt particularly in the grain, which gains a greater weight, a finer appearance, and a better commercial quality.

Among the many agriculturists who have attended the open meetings of our rice station are many who now employ potassic fertilizers, convinced at last of their utility for the improvement of the grain. However, there may exist lands in which the natural richness in assimilable potash makes fertilization with its salts inopportune; but it is none the less certain that in many others this fertilizer possesses undeniable value.

* * * * * *

It is very important, in order to obtain the greatest possible benefit from a fertilizer, to know how to apply it conveniently at the opportune time. Rice is a plant very sensitive to slight variations in temperature. It is, then, easy to comprehend that it is not a matter of indifference, fertilizing it at one time and doing so at another. This is the reason we are under the necessity of studying out the most rational systems of applying the fertilizers at the opportune times.

As regards the phosphatic fertilizers, it is generally well to

apply them before working the ground, so that the phosphates may have time to begin their transformation, and that they may be ready to aid the rice in its gradual development. Working on this principle, the phosphatic fertilizer is applied to loose, sandy soil before the ploughing; to clayey soils likewise a little before. When a plant to be ploughed under has been sown, the fertilizer is applied in autumn, so as to aid directly the plant in question. According to the slowness with which the phosphate will act, it should be applied earlier or later; thus, Thomas-slag is almost always applied in autumn, especially on clayey soils.

The potassic fertilizers are ordinarily applied before the cultivation of the field.

As to the nitrogenous fertilizers, and especially the ammonium sulphate, the time of their application has generally been determined by the prejudice against stimulating the development of weeds; for, as is known, these nitrogenous fertilizers, at the same time that they cause a more rapid vegetative development of rice, favour also and in the same manner the weeds which abound everywhere in our rice fields. This is why many agriculturists think only of the multiplication and development of the weeds caused by these fertilizers, and continue to apply the ammonium sulphate only after the weeding, with the object of having the fertilizing substances reach the rice only.

However, it is proved that this late application exercises its effect too late, when the rice has already begun to suffer from the want of nitrogen. Moreover, by causing an excessively vigorous vegetative development of the rice, the late application materially retards the maturity and incites a great growth of the stems, while it leaves the grain more subject to diseases, not uniform, ripening irregularly, with green seeds, which results in great loss, and the depreciation of the product.

The most rational practice, now generally followed, consists in applying the ammonium sulphate at the moment of preparing the land, working it in with rakes, so that it may thus help the rice in the first periods of growth, without on any account thinking first of the weeds, for it would be a grave mistake to injure the rice just to avoid favouring the development of the weeds. In some cases (and this is the better method) we apply the ammonium sulphate twice—a part before the seeding and another part after the weeding; this is the most rational means of making the fertilization serve the daily growing need of the plant for nitrogen.

Novelli went on to say that excessive acidity, resulting from constant submergence, injures the rice. On

land constantly in rice this acidity often exceeds 12 per 1000, expressed in cubic centimetres of normal potash. To correct this condition, the advice is to apply 12 to 15 quintals of quicklime per hectare. This is effective for two or three years.

In a very recent paper[1] Novelli describes the application of a fertilizer containing 15 per cent of soluble phosphoric acid, at the rate of 7 to 8 quintals per hectare, two-thirds before flooding the field and one-third when the field was dried after the first weeding—*i.e.* along with the nitrogenous fertilizer. The estimated yield was 60 quintals of paddy and 90 quintals of straw, removing 0·4 per cent of phosphoric acid in the straw and 0·9 per cent in the paddy. The rice was *Chinese originario* or *abbondanza*, a variety which, with other very similar types, is the kind most widely cultivated in North Italy. It is recalled that this is the variety known in California as "1600" or *Colusa*, which is very similar to *wataribune*, but earlier. The results of insufficient phosphorus are summed up as late ripening, susceptibility to disease, and incomplete filling of the heads.

The kind of rice described by Novelli as most grown in Italy is the familiar Japanese type, with short, roundish, even, hard kernels of the finest milling and unexcelled cooking quality. The type known as Piedmont has somewhat larger and flatter kernels. In milling quality it is inferior to the Japanese type, but superior to the long-grain rices. It usually contains an admixture of red rice. A paper by Branchini[2] states that several farmers began in 1908 to experiment with directly imported Japanese varieties. *Jamatoriki* gave the best yield, 62·26 metric quintals per hectare.

In 1912 Novelli[3] expressed the hope that the Italian Government would exercise control over the purity of

[1] *Giorn. di Risic.* 12. (1922), 20. Reviewed in *Internat. Review*, 13. (1922), 493.
[2] "I risi dell' avvenire," *Il Villaggio*, No. 1809, p. 99, 1911. Review in *Internat. Inst.* (1911), 559.
[3] Novelli, N., "Una nuova varietà di giavone che si diffonde," *Giorn. di Risic.* 2. (1912), 305.

imported seed, the occasion being the introduction of weeds along with the seed rice. *Panicum phyllopogon* and *P. erectum* were then recent introductions of increasing seriousness; but there had just appeared another and worse, hard to weed out because of its resemblance to rice, which he therefore called *Panicum phyllorhyzoide*. It was first observed in introduced varieties, *Sekijama*, *Omaci*, and *Fukushima*. From his description, it appears to be what is called in California Japanese millet, having come in in the same manner and at about the same time. Marcarelli,[1] a few years later, said that this *P. phyllorhyzoide* and *P. Crus-Galli* were the worst weeds of Italian rice. The means recommended for dealing with them were: good preparation of the land, the use of well-decomposed manure, clean seed, careful weeding, and, especially, the mowing, several times during the season, of all unsubmerged rice land. Novelli also advises the use of water to control these weeds. His method is to submerge the seed deeply, withdraw the water long enough to let the rice root well, and return it, deeply enough to kill the weeds and even weaken the rice. The rice recovers perfectly, later.

Rice-growing has much in common in Italy and in the United States, especially in California. The differences are chiefly functions of different density of population. The Californian uses machinery to enable him to cultivate and harvest great areas. The Italian also has specialized notably in the use of machinery, uses tractors to a considerable extent, and has studied them most carefully; but the scale of his operations bars the use of the powerful machines which are so important in California cultivation. He does not use binders to any extent, because the supply of labour and its cheapness enable him to avoid their wastefulness.

In one phase of mechanical development he is far ahead—the use of driers. Some of these are described

[1] *Giorn. di Risic.* 5. (1915), 248. Review in *Internat. Rev.* (1915), 1412.

and figured in Guardiola's paper, already cited. Tarchetti[1] describes a portable "esiccator" for paddy, made in Vercelli, said to have a capacity of 112 cwt. of paddy.

Seed drills are generally used. But the advantages of transplanting are becoming widely recognized and the practice is gaining. Mechanical planters of seedlings are sought; such have, indeed, been tested, but without success.

Chiappelli[2] reports on a prize competition opened in 1920 by the Vercelli station to encourage transplanting. The increased returns from the land gave a large margin of profit over the added expense. The late demand for the land, for transplanted rice, made it possible to plant an early variety, following the harvest of wheat, early in July. In general, the increase in yield by transplanting was 7 or 8 quintals to the hectare. Also, the kernels were heavier and the ripening was more uniform. The same paper reports the culture of carp in the rice paddies, reminding one of the gold-fish culture in Java.

Novelli[3] states that it is common practice in Mantua, Verona, and Bologna to sow wheat broadcast before the rice harvest, and that very productive wheat has been obtained in this way in Mantua and Venetia. The sowing must be about the 1st of October, and twenty to thirty kilograms more of seed per hectare is used than by the usual method. The rice is cut to a rather short stubble, and the surface drainage must be looked after very carefully. Phosphatic and nitrogenous fertilizers are applied freely, at a cost about offsetting the saving by not ploughing. The scarcity of weeds in the wheat, along with the saving of time, recommends this practice for experiment in the United States, where a rotation of crops has already been forced in parts of the south, and must soon become an important problem in California.

[1] *Giorn. di Risic.* 4. (1914), 88. Review with figures in *Internat. Review* (1914), 1211.
[2] *Ibid.* 11. (1921), 105; *Internat. Rev.* 12. (1921), 1413.
[3] *Ibid.* 10. (1920), 129; *Internat. Rev.* 11. (1920), 1268.

CHAPTER VIII

THE USES OF RICE

The uses of rice might be treated at great length by including analyses of products and arguments based on them; but such data mean little to the majority of readers and are usually of no interest to growers. Some of them are essential to millers and should be appreciated by breeders; to such people they are available elsewhere. There are accordingly presented here only sufficient tables of this kind to convey a clear understanding of the general subject.

The great use of rice is of course for human food. Among the foods of men it holds the foremost place, the estimated normal yield being four hundred and forty billion pounds [1] of rough rice, against two hundred and seventy-six billion pounds of the second crop, wheat. To fit it for use as food, the hulls have first to be removed. This leaves "brown rice," whatever its shade. The outer coats of the kernel are then removed, leaving "white rice," what is taken off in this process being the bran, according to the usual American diction. Rice meal may be bran, or bran and polish together. The word "rice," without any qualifying term, when it does not refer to the plant, usually means white rice or polished rice, not paddy or brown rice. Polishing consists of beating the kernels of white rice with flappers, formerly of leather, now usually of felt; what is removed in this process is called the polish. The

[1] Internat. Inst. Agr., *Crop Report and Agric. Statistics*, 13, II. (Jan. 1922), 5.

making of white or polished rice from paddy or rough rice, once altogether a home operation, then partly done at home and partly by small, local, primitive mills in the lands where rice is the staple crop and food, tends more and more to be done by modern mills, for the rice of local consumption as well as almost entirely for the rice of commerce.

The final process of milling is coating or glazing. In the United States, the materials used for coating are talc and glucose. Elsewhere, steatite, mica, kaolin, or gypsum may be used in the place of talc, and glycerine or mineral oil in the place of glucose. The purpose of coating is supposed to be to make the rice more shiny and attractive. But it serves also to protect the rice against attack by insects. In the United States the mills turn out a considerable part of the new crop uncoated, as it is due to be consumed before the advent of warm weather when weevils become dangerous; but all rice milled in spring and summer is usually coated. Coating has essentially nothing to do with the food value of the rice.

"Cargo rice" is that from which most of the hulls have been removed. Formerly the chief form in which rice arrived in Europe from the Orient, it is of decreasing importance, and is now an insignificant part of the export from Saigon and Bangkok. Rough rice is the least perishable form, cargo rice and brown rice being the most perishable. In mill terminology, the hulls are removed by the "stones," and the "hullers" remove the bran. If milling is complete, the products are hulls, bran, polish, and rice. "Screenings" may be added to this list; but the commonest use of this word is to indicate more or less finely broken kernels of rice.

The rice in turn is variously classified, commonly as head rice, broken rice or screenings, and brewers' rice; to these a "second head," composed of the larger broken kernels, is sometimes added. Without the least superiority so far as food-value is concerned, the head rice, comprising the whole kernels (with a certain

permitted content of the broken ones), is decidedly more valuable than the broken rice because of its appearance. Growers and millers have therefore a common interest in producing the greatest possible proportion of it. The factors under the control of the growers which contribute to this result have been discussed in Chapters IV. and V. According to the quality, as determined by colour, cleanness, uniformity, absence of broken grains and of seed of other kinds, the head rice is graded as fancy, choice, and line or standard or export. Rice below the standard in any of the above respects, or too moist, cannot receive a certificate of grade, and must be sold by sample. Sample grade rice may receive as good a price as graded, but is likely not to do so.

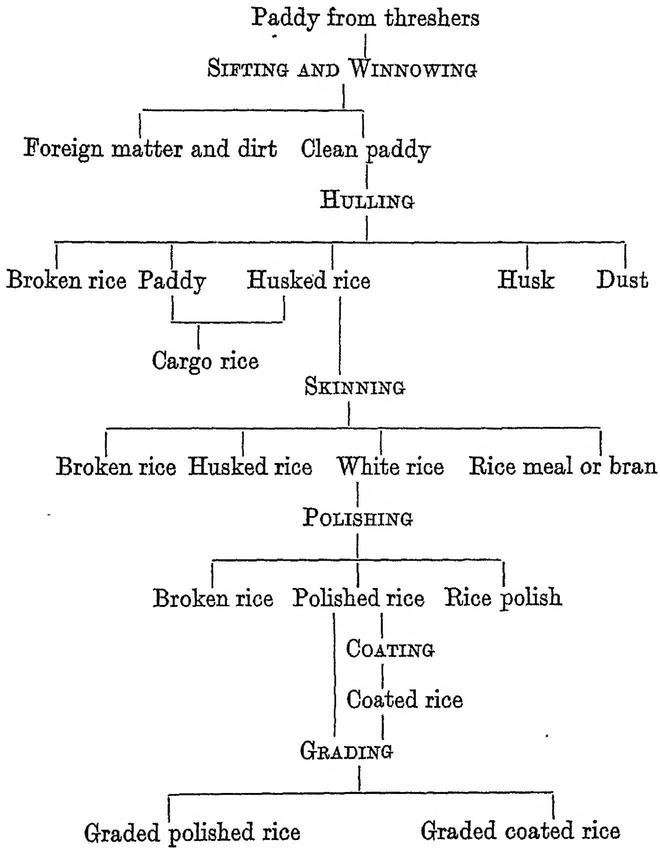
The segregation of the products in complete milling is shown graphically by the diagram on the following page.[1] In this diagram, broken rice includes brewers'.

A peculiar preliminary treatment, preceding milling, known as *josh*, is described from Sind.[2] The paddy is cleaned, then boiled, and heated again, and then dried. "By being semi-cooked, the husk easily separates in the mill, and there is no breakage of grains. Besides, it is claimed that such rice has better keeping qualities, and does not deteriorate when carried on long sea voyages. The rice prepared this way fetches the same price as the usual sort, the extra expense of boiling, etc., being covered up by the gain in weight during the *josh* process." Untreated paddy yields in Sind 65 per cent of rice; after the *josh* treatment it yields 70 per cent. All rice so treated is exported, the rice from this district going to Persia and Ceylon.

In Malaya and British Guiana the rice intended for local consumption by Indian peoples is steamed or parboiled, but that for Chinese use is not so treated. In California, rice leaving the stones is sometimes passed through a steam jet to facilitate removal of the bran.

[1] From *Indian Trade Enquiry Reports on Rice*, issued by the Imperial Institute, London, 1920, p. 143.

[2] Abder Rahman Ishaq, "Rice Cultivation in the Larkhana District, Sind," Dept. Agric. Bombay, *Bull.* No. 99 of 1920.



A detailed discussion of rice as a food would be superfluous here. Rice forms less of their diet than probably a majority of humanity would like it to do. It forms a smaller part than it well might of that of some lands, notably the United States. On the other hand, it forms too large a part of the diet of some of the peoples who use it as a staple and raise almost nothing else. In such cases the fact that complete milling removes the vitamines, as well as much of the proteid and fat, is a matter of dietetic importance. Brown rice is a decidedly richer and more complete food

than white. The writer makes a practice of having it on hand because he likes its flavour, as do no few people who have learned what it is. But the market demands polished rice as a matter of appearance, just as it demands white flour. Brown rice is by no means as coarse a food as is whole wheat.

A fair general composition of polished rice is:

Moisture	13 per cent.
Protein	7+
Carbohydrate	78, practically all starch.
Fat	0·5+
Ash	0·5-1·0

If the moisture is less than 13 per cent the other constituents are proportionately increased. The moisture in commercial rice is rarely as low as 11 per cent. If it exceeds 14·5 per cent the keeping quality is endangered, and the United States inspection service will not issue a certificate of grade.

Brown rice is materially richer in fat and protein, besides having a sufficient vitamine B (oryzanin) content to prevent the bad results (beriberi) which sometimes ensue from a diet of polished rice without sufficient other bearers of these essential food-constituents.

As regards cooking there is a diversity of practice, properly, but not always, correlated with diversity of taste. Chinese in general prefer their rice harder than do most other peoples. But it is doubtful if anybody really prefers the soft, mushy stuff often served as boiled rice to rice so cooked that the kernels remain distinct and free. Contrary to common belief, at least in the United States, any good rice can be cooked in the latter manner — Honduras, Piedmont, Javanese, Japanese, Patna, or any other—provided that it be thoroughly washed first, and that *it be not stirred at all* while cooking. This can be done with much or little water or with steam, over a fast or a slow fire. The varieties do differ in the amount of water the rice will absorb, and in the time required for good cooking. But I have no

experience with any non-glutinous rice which cannot be boiled to the desired consistency, with the kernels free, if the water and time are properly adapted to the variety and the strength of the fire. If it is desired to conserve the flavour of the rice, only as much water should be used as will be evaporated or absorbed by the rice, and none should be poured off. If the heat, after boiling begins, is only sufficient to keep up a very gentle simmering, most rice can be cooked well in this manner, using not more than two measures of water to one of rice.

Another and more widely used method is to use a large excess of water, and pour and drain off the surplus when the rice is cooked through. The Orientals who employ this method prefer the exceedingly mild flavour of the resulting rice to the more marked and distinctive taste resulting when the easily soluble materials removed by the discarded water are retained by evaporating whatever water the rice does not absorb. This extracted material is sufficient to make the surplus water worth keeping for soups and other eventual use; but it is usually thrown away. According to the writer's personal taste, the most perfect rice he ever ate was in Java, where it is steamed in a large hour-glass-shaped copper vessel, with boiling water in the base, and the rice in a hollow cone of woven bamboo which fits into the flaring top.

Of course there are other ways of cooking rice besides boiling it, although the most of the rice dishes found in cook-books have boiled rice as their base. Many delicious dishes are made by cooking rice in deep fat instead of in water. Brewers' rice makes an excellent mush, cooked like meal of any other kind. Puffed rice is a proprietary food, made by exploding the kernels of polished rice. *Pinipig* is a prized seasonal food in the Philippines. The rice is harvested in the dough, and gently roasted, which puffs it very moderately. It is then pounded, which readily removes the hulls, some of the bran and the germ, and leaves the rest of the kernels

crushed and flattened. They are then an excellent cereal food, of the general class of corn flakes and wheat flakes, well worthy of the widest use. Pinipig is made of any non-glutinous rice, and is common in Philippine markets as the harvest time comes on.

Rice flour is too exclusively composed of starch to be used alone to make bread. A mixture of one-third rice and two-thirds wheat flour makes a remarkably white and fine-grained bread. Whether or not a rice variety can be found or bred with real gluten content adequate for bread-making, has not been investigated, nor has the possibility of increasing the gluten by cultural treatment, as has been done by Gericke with spring wheat and oats. As the so-called glutinous rices contain a carbohydrate sticky substance instead of true gluten, they offer no prospect at all in this direction. For making various other things than bread, as cakes and waffles, rice flour can be used without any admixture of wheat. Rice yields a very fine-grained, smooth, firm starch, good for the laundry and for paste, but which finds its greatest single use as face-powder.

Glutinous or sticky rice is an article so distinct that in many of the lands where it is grown it has a name by itself, and is not understood to be included under the general name of rice as a food. Statements that such rice is anywhere the staple food are probably due to confusion of mountain and glutinous rices. It is, however, the chief constituent of pastries, wherever grown, and of these and candy-like confections made from it, there is a vast variety. It is a really valuable food material with which the Occidental races have still to become acquainted. About 8 per cent of the rice area of Japan is planted to such varieties, and in China the estimate is as high as 20 to 30.

Rice is used very widely to make fermented beverages. This may be an industry of people of primitive culture, like the Igorots and other mountain folk; or a nationally established industry, as is the *saki* manufacture of Japan; or the rice may be used with other

grain or in the place of other grain in the breweries of lands which import it for this purpose. The finely broken kernels, the presence of which would lower the market value of rice sold for food, is as good as any for fermentation, and naturally finds this market, whence the name of brewers' rice.

The saki manufacture in Japan is a thoroughly and scientifically regulated and operated industry, in which the active fermenting organism is bred in pure cultures to ensure a uniform product. The Indian rice beer ferment is called *bákhar*.[1] The "yeast cakes" are obtained from many sources, and are of different composition, the active constituents being various yeasts, besides *Mucor*, *Aspergillus*, etc. Their activity and the quality of the product depend upon good yeast, which must have a chance to work unhindered by other fungi and bacteria. A study in Indo-China [2] has shown that 30 per cent of rice may well be used in the brewing of pale beer. In the Chinese and native distilleries "Chinese yeast" is used, and distillation is immediate. Vinegar and acetone are also produced. But the tropical Orient has cheaper sources of alcohol and allied products in cassava and, where it occurs, in the Nipa palm, as well as in the waste and by-products of cane-sugar manufacture.

Rice bran and polish are valuable concentrated feed for stock. Bulletins on its use for hogs and milk and other cattle have been issued in recent years in Italy, Texas (No. 121, 1916; No. 224, 1918), and Arkansas (No. 128, 1916; No. 142, 1918). The hulls are valueless, and injurious if present in too great proportion; in stock feed sold in Florida their presence is prohibited as "deleterious and unwholesome." Rice stubble is valued for various reasons, depending upon what is left by the harvest. In California, where there is great waste in the harvest, hogs and turkeys thrive on it.

[1] Hutchinson, C. M., and Ram Ayyar, "Bákhar: The Indian Rice Beer Ferment," *Mem. Dept. Agric. India*, Bacter. Series, 1. (1915), No. 6.

[2] Samuel, M., "Note sur l'emploi du riz en distillerie et en brasserie," *Bull. Agric. Inst. Scient. Saigon*, 2. (1920), 109.

Hogs on rice stubble produce very fine carcasses, require almost no finishing in the pen, and are regularly underguessed as to weight. In the Orient little grain is left in the field after the harvest, and the chief source of value in the pasture is the weed vegetation.

The hulls are in most places a waste product, produced in large quantities, and for which there has been much effort to find a use. They burn with a very large residue of ash, in spite of which disadvantage they are used for fuel where better fuel is scarce. This is done in Italy and in many densely populated Oriental lands. The results of attempts to make briquets of them have not been very satisfactory. In Bangkok all of the power to run the mills is obtained by burning the hulls. Dry distillation, driving off a fuel gas, will be the best way to use them as a source of power, heat, and light. When a mass of them burns naturally, such distillation occurs in the interior of the mass, in advance of more complete combustion, and the heavy liquor set free is used in parts of the Philippines as a home medicine. The charred hulls have been used in New Orleans as a substitute for bone-black in refining sugar. There have been many experiments at least, with the hulls as a filler for concrete.

The weight of straw almost always exceeds that of the grain. While the green rice makes fair hay, the straw is practically valueless as feed for stock. In the Orient it has, however, a variety of uses, as for making mats and sandals. Because it is tougher and less subject to decay than most straw, it is superior for packing many kinds of articles for shipment—hardware, furniture, crockery, etc. For this use it makes a good and cheaper substitute for excelsior. It is tough and pliable enough to be wrapped into bands and sheets, as is done with excelsior, for the most convenient and secure packing, and a promising market for such use is developing in California. It is worth while to remember, at the same time that growers welcome a prospective income from the sale of the straw, that with it considerable mineral

food and potential humus are removed from the land. If the ashes from a burnt straw-stack are spread out evenly over an acre of the field the improvement in the following crops is conspicuous for at least two years. And the long stubble, ploughed under, improves the land very evidently, for rice and for other crops.

The thin, fine Japanese paper called rice paper is made from a very different plant. White paper of fair quality can be made from rice straw, but its manufacture does not appear to be economically practicable. The straw does, however, yield a pulp good for the manufacture of cardboard. A mill is in operation in Louisiana, manufacturing corrugated fibre boxes from it.[1] This mill pays $6.25 a ton for the straw, delivered. The straw yields 65 per cent of dry pulp, and the mill has an output capacity of forty tons a day.

In the Philippines, in Pampanga province, mushrooms are raised industrially on rice straw. The chopped straw is put into beds, usually under open bamboo shelters. The beds must be ten inches deep, after tramping. They are moistened and kept moist by either of two methods. One is to use rice wash, that is, the water in which rice has been washed before cooking. The other is to use a weak brine, a solution containing a spoonful of salt to eight litres of water. The mushroom is *Volvaria esculenta*, the common mushroom of the Philippines on abacá and banana waste. It appears without artificial inoculation on these beds, irregularly throughout the wet season, and can be kept coming, into or through the dry season, if the beds are kept properly moistened.

Vivencio's [2] experiments at the College of Agriculture led him to conclude that on rice straw *Volvaria* can be grown by artificial inoculation, as easily as can *Agaricus* on any medium. Since they are practically indistinguishable in flavour, the consumer can have no choice

[1] *Bull's Eye*, 2. (1922), 9.
[2] Vicencio, A., "A Study of Mushroom Culture in the Philippines," *Phil. Agric. and Forester*, 5. (1916), 119.

between the two mushrooms, unless because the substratum of the cultivated *Volvaria* makes more of an appeal. The *Volvaria* appears in the open as readily as in the shade. The thicker the rice straw in the bed, the greater the probability, at the college, of getting the desired mushroom without artificial inoculation. Edible *Volvarias* are found in most lands, and it is likely that any of them can be grown in this manner.

CHAPTER IX

GENERAL CONCLUSIONS

As a conclusion, there remain for brief discussion certain matters which involve joint consideration of rice in many lands, and certain relations between rice culture and human affairs, beyond those, already dealt with, which have to do directly with the handling of rice in the several countries.

Commerce in Rice.—Throughout the civilized world finished rice, being an important food, which in most places is not a home product, is an article of local trade. What is in order here, however, is not a treatment of rice in this connection, but of its place in international commerce. For this purpose, all that is necessary is to assemble some of the data already presented, mostly in Chapter VII.

It is recalled that the most of the rice of world commerce comes from three countries, India, Indo-China, and Siam. The actual volume of world trade in rice varies greatly from year to year, chiefly under the influence of the amount of the gross exportable surpluses. Many official statistics have already been presented. Because world conditions have been very unsettled for nearly a decade, and conditions longer ago have been largely outgrown, it will best serve the purpose to present here the following rough approximations to what may be regarded as normal surpluses for export:

India	2,600,000 tons
Indo-China . . .	1,500,000 „
Siam	1,300,000 „
United States . . .	300,000 „
Italy	80,000 „
Spain	50,000 „
Brazil	50,000 „
Persia	50,000 „ (?)

Korea and Formosa are ignored in this statement, being regarded as parts of Japan. A small surplus for export is produced also by Madagascar, Iraq, and British Guiana, and in some years by Egypt.

Ten years ago the international trade in rice was said to amount to 6,400,000 tons. That figure included a large volume of re-exports. Including these, the trade has increased materially, but with very considerable changes in detail. Holland formerly regularly exported more than 200,000 tons, and Germany was not far behind. The European rice-milling business may never recover completely, because of the tendency for rice to be milled while in the lands of origin. Still, the volume of re-exports remains large, Singapore and Hong-Kong being leading emporia of this trade. There is also some international trade in rice exported from lands which import it in larger quantities; Java, China, and Japan are such lands.

The Orient is not merely the source of the most of the rice of commerce; it does also the most of the importing. China, Japan, British Malaya, and the Dutch Indies may each import more than half a million tons a year; Ceylon more than 300,000 tons; the Philippines a varying amount, sometimes 150,000 tons. Mere spots on the map, like Mauritius, may import more than 50,000 tons.

As to prospective production, there is likely to be for some time an increasing surplus for export from Siam, Indo-China, and Brazil. Indian production, too, increases, but her consumption may be expected to increase at least as rapidly. The East will in general provide a market for increase in crops anywhere in the

East. Doubling production in less than a decade did not make the Philippines cease to import. It is not many years since Japan became a net importer, but she imports steadily now, in spite of having acquired the large Korean surplus. The advance of Malaya and the Dutch Indies to foremost importing lands is also recent. A hundred years ago the Burmese rice industry was in its infancy, a few coasting vessels handling the surplus. Fifty years ago India without Burma was a leading factor in the rice exporting business, furnishing more than one-third of the world's commercial rice. Now, a full million tons of Burmese rice a year is needed to make up the deficit in the rest of the Empire. Two things happen steadily in the East: with peace, the population outgrows the rice-producing power; and with wealth the consumption *per capita* increases in a manner never anticipated, and to an extent which it does not now appear safe to try to fix.

As a summary, then, there has for many years been a remarkably rapid increase in rice production, and this increase continues; but experience justifies the forecast, that future increase in production will at most no more than meet the growing demand in and near the places of production. There is no evident reason to fear that rice produced in Europe and the Americas will encounter increasingly serious competition from Oriental surpluses.

Economic Summary

This caption is intended to cover a summary discussion of the cost of producing rice, of the economic status of rice growers, and of the density of population which rice is able to support. The cost of producing a given weight of rice may be determined from the yield per acre and the cost per acre. Such statistics have been presented in full for California, and partly or completely omitted in many cases, because I mistrust the available data. To determine cost per acre, the use of the land, as well as of labour, must be taken into account; and

the former usually receives inadequate attention. If rental is a share of the crop, the direct and evident cost of the crop is clear enough; but the real profit or loss of the landowner must be known before the economic status of the industry can be appraised. I have satisfactory data on this point only from California and the Philippines; and even in these depletion of the land is ignored. The problem is a complicated one, and I am attempting here only to throw some light on it from various angles, without venturing to draw positive conclusions.

In the description of the rice culture of the various lands, data have been given on the production per acre in the most of them. The diversity in different lands is quite remarkable, the range being from 500 or 600 lb. of clean rice per acre in Ceylon and the Philippines a few years ago, to a wonderful record of over 66 cwt. in 1922 for *Benlloch*, in the Spanish district of Alberique.[1] On the whole the best yields are from temperate lands —Spain, Japan, and Italy. This is largely due to the use of fertilizers, but the difference is great and constant enough to suggest that climate may be a factor.

Since the use of the land is a factor in the cost of production, it might be expected that where land is most expensive there would be found the greatest effort to obtain maximum crops. It is to be observed that in general land is most valuable where population is most dense, and that in such places transplanting is universal practice with paddy rice. Except for this feature, the relation between land value and yield is that yield determines the value, rather than that value of land determines the methods used. The Spanish rice fields are among the most highly valued rural farm lands in the world—$1600 an acre, according to a statement at the Valencia Congress. But Ceylon land is held at a high figure, so high that the production of rice there makes a ridiculously small return on it. And this condition, while common in Oriental lands with low

[1] Personal advice from the Director of the Sueca Station.

production, does not result in the intensive cultivation familiar in China and Japan.

Production *per capita* is a chief factor in determining the direction and volume of business in rice, and so, through its influence upon the relation of supply and demand, in determining the price. Statistics on this point are easily obtained where there are any statistics at all, but have little interest except that just indicated. They do not show the rice-producing power of a given population; for, on one hand, only part of a population is so engaged; and on the other, the number so engaged may at times be greater than data on population would suggest. Thus, Burma is foremost among Oriental lands in yield *per capita*—996 lb., according to the *Indian Trade Enquiry Reports*; 10·3 piculs (1670 lb.), according to van Gelderen. But this is harvested with the help of a vast number of seasonal immigrants—400,000 in 1911, according to a census estimate. The Spanish rice fields draw labour from two hundred miles away during their busy times. And in California the rice region has, during the few harvest weeks, several times its normal population. If this seasonal help be ignored, there are records for Californian counties, in which rice is only one of several crops, of more than ten thousand pounds of rice per head of the fixed population; and for single ranches and groups of ranches, even this figure may be multiplied by ten.

To get a common local value for the land and labour cost of producing rice, the former may be measured in terms of the latter. In California, the value of an acre of good rice land, including diking and the water right, is not commonly more than twenty-five days' wage for common labour; and the yearly rental, including provision of water by the owner, does not usually exceed five or six days' wage. In the Philippines, the rental varies greatly, but may be not much in excess of this. But an acre of graded rice land there is worth about a year's wage. And in many parts of the East land is still far more highly valued in proportion to labour,

though the rental may pay almost no interest on the supposed value.

For a comparison of the efficiency of methods, or of cost of production, the labour figure wanted is the number of days applied to each acre, or to the production of each sack. In California, if weeding is not practised, an acre of rice is likely to receive hardly two days of man-labour prior to the threshing; besides this, there is perhaps one day for one horse, and a fraction of a day for machinery. In the Philippines, up to the same stage, Camus figures that paddy rice receives more than fifteen days of man-labour and about six of woman-labour; besides nearly five days of animal-labour—more than the equivalent of the horse and machine work required in California. The ratio of effort in the two lands is greater, if judged by the sack, because yields are heavier in California. As wages in the Philippines and in California differ in a smaller ratio than do the numbers of days required to produce equal weights of rice, it follows that the labour cost is greater in the Philippines, measured in money, as well as measured in days.[1] In fact, seed, water, and taxes are the only considerable elements in the cost of a crop which are usually higher in California. It seems to follow that, where land is available for rice culture by California methods, and the climate permits their use, rice so grown is in danger from Oriental competition (assuming that the Orient can produce a surplus for export) only in the case of lands where either the wage is considerably less than one-tenth as great, or else the crops are materially heavier. In practice, Japan produces much heavier crops, but imports California rice.

Status of Rice-growers.—There is a prevalent belief that rice-growing is necessarily associated with wretched economic conditions, that it is characteristically the work of slaves or serfs. It is certainly true that the bulk of the world's rice is raised where the people are

[1] Still, if California and the Philippines had to compete for a rice market (which practically cannot happen), the Philippines would get it.

poor. It is also true that in parts of the Orient itself rice-growers as a class are poorer than producers of certain other crops, notably those which, like the coconut, require years before they begin to produce. This follows naturally from the fact that the latter class of crops can be planted only by those able to wait during years for returns to begin to come in. More than this, the perennial crops in question are as a rule those of districts where population is not dense, suited to such districts because the labour of the individual cares properly for a relatively large area in such crops; and such districts are economically strong because a larger area is available to serve each man's wants.

On the other hand, rice production is nowhere the business of the really destitute. The rice-grower is his own master, as the plantation labourer, in sugar, for instance, is not. It is becoming a recognized principle of rural economics that in one-crop regions individual farm ownership tends to give place to tenantry. The most typical one-crop region of the globe is surely Southeastern Asia. But in many parts of this region the present trend is as unmistakably toward individual ownership as it is in the opposite direction in the cotton and solid wheat districts of the United States. Rice-growing is the occupation of the great middle class of the Orient, never of the dregs of the population.

Before one seriously regards wheat as typically the crop of more prosperous peoples, it would be well to remember how largely wheat is the crop of *sparse* prosperous populations; and how largely, in recent years, virgin lands have been yielding their first fruits in the form of wheat. Japanese land produces wheat very well, but Japan would starve if it were allowed to displace rice. Wheat, barley, maize, and millet grow side by side with rice in India and China, but not an acre of good rice land is sacrificed for any other grain. If rice culture be compared fairly with the growing of any other great food crop, and the issue be not confused by comparing lands or civilizations extremely different in other

and independent respects, no ground at all will be found for regarding rice as the crop of the poor.

The low standards of living in the great rice lands would, of course, if they could become effective in this connection, constitute a menace to the rice industry of lands where life is more expensive. If the competition for a market for rice were very keen, the world's supply maintaining itself above the demand, the effect would inevitably be either to lower the standards of living of rice-growers where these standards are now high, or to stop rice production in such places; actually, such a condition would drive such growers into other work in most places. But, since wages and standards of living are rising very decidedly in the Orient, and the consumption of rice there increases with the power to buy, ruinous competition for a market is most unlikely.

Rice and Population.—A relation between rice culture, and particular methods of rice culture, on the one hand and density of population on the other has been suggested repeatedly in the preceding pages. This relation will now be examined, first in its economic and then in its social aspects. Many writers, seeing rice to be the crop of the congested millions of the Orient, have assumed that it will produce food for a denser population than will any other crop. The case of Java, already presented in some detail, shows that this is not quite true. Java resorts to maize, manioc, and the sweet potato, in the first place, because they thrive on land not suitable for rice. Parts of the Philippines are maize districts for the same reason; but, besides this, manioc will produce more food from the unit of land.

While no question is of more profound human interest than the capacity of different plants to produce food from the unit of land, data for a valid comparison are wanting. The performances of rice in Spain, sugar in Java and Hawaii, potatoes in Germany, maize in Iowa, and manioc, yautia, and the grain sorghums in experimental cultures at different places, are not fairly comparable as demonstrations of the inherent productivity

of the several plants; but manioc (cassava), yautia, and sugar, at least, can almost certainly be made to produce more than any treatment can get from rice.

An exceedingly interesting first study of the economic relation between rice culture and density of population has been made by van Gelderen.[1] He shows a population in Java of 266 per Km^2,[2] exceeded by no independent state in the world, nor by any political division with corresponding population. Corresponding figures are: for Belgium, 252; for England, 239; Japan, 135. The figure for Bengal is 223; rice is there a more exclusive diet than in Java, the finished rice production being about 400 lb. *per capita* of the population, and almost all locally consumed. There are Javanese districts incomparably more densely peopled, and some of these are self-feeding. Keboemen, for example, with 902·9 per Km^2, produces 472 lb. of rough rice *per capita*, which is within the range of amounts supposed to support a people.

Such statistics as I have been able to find on *per capita* consumption, where people are supposed to "live on rice," range from 250 lb. to 600 lb. per year. The actual consumption, of course, depends upon the exclusiveness of the rice diet, and the sufficiency of the total ration.

A real surplus for export can be produced only where the population is less dense, in proportion to the rice land area, than it is in Java and Japan. Lower Burma has only 30 inhabitants to the Km^2, and the highest figure for any considerable rural district is 71. Siam has only 18, and the Mekong delta only 65. Census data indicate that, under the conditions of a decade ago, 60 per Km^2 was a critical figure in the Burmese rice region, the tendency being toward immigration below this figure, and toward emigration above it. With the disappearance of neighbouring territory less densely

[1] Van Gelderen, J., "[illegible] en landbouw op Java," Dept. van Landbouw, etc., *Mede [illegible] Kantoor*, No. 8. The reprint is not dated, but the paper was read in May 1922.

[2] Multiply by 2·5 to get a rough figure per square mile.

populated, the conditions of industry and migration change, and this critical figure rises or disappears. With these changes the surplus for export may increase for a time, while labour, not land, remains the factor controlling production. But finally, with increasing population, whatever the methods of production, the surplus must decrease and cease to exist. There are no data as to the point where increasing population results in a decrease of surplus, nor valid ones as to that higher point where it makes any surplus impossible. These points are of course far higher where the methods of production are such as result in heavy yields, as in Japan, than where field fertilization is unknown; but no methods can keep such points from being reached.

Social Considerations

The only difference between social and economic considerations, in many cases, is in the point from which the questions are viewed. Thus, we have just discussed standards of living and density of population in their economic aspects; and have now to review wealth, usually the basis of economics, in connection with density of population, in their social aspects.

In a number of places, attention has been drawn to the fact that paddy rice culture is remarkable in the field of agriculture, for the investment it demands in realty, and for the immobilization of this investment. This immobilization is so complete that the investment cannot be removed, can hardly serve any other purpose, and is not even easily destroyed. In amount this investment varies widely, reaching, at the extreme, to some thousand days of labour per acre, applied by the "Igorots" to land without value before it is worked upon. In America, the contouring of the land is inexpensive, and the dikes are easily removed; but it is not unusual for the service of water to the land to cost more than the land was previously valued at for other use. For a comparison of the fixed investment in rice

culture and in other crop-growing, the original value of the land is a convenient term in which to measure the cost of converting it to paddy. Where rice culture is intense in the Orient, this is an impracticable term, because the value of other land than paddy varies inversely with the anticipated cost of such conversion, and land susceptible of it is now usually valued on this basis; but a calculation of this kind is valid where a surplus of land remains. In the Philippines, leaving out of account districts so unsettled that land is very cheap, I have had several opportunities to get such figures, and believe that conversion to paddy multiplies the value by three or four, in general, rather than by two.

So far this is economics. The social feature of it is that the investment of effort required to develop paddy land immobilizes the population itself. Now, whatever its past, any people tied down by immovable investment presently becomes peaceable and peaceful. With peace the population increases and multiplies. A philosophy of peace and conservatism develops. The ancestors rest in the soil, and both are revered. Rice-growing peoples are typically not aggressive; they cannot afford to be, have little inducement to be, until the pressure of population becomes insupportable, and by that time they are likely to have no spirit for aggression, and to have adopted a code which prohibits it. With the loss of fighting spirit, they become easy victims of warlike peoples. But the latter, in the nature of the case, are not rice-growers, and therefore govern and exploit, rather than displace the settled race. India and China have been conquered over and over, and simply absorb their conquerors.

Thus the nature of paddy rice culture underlies and explains the density of population, as well as the stability of the human cultural systems, of India and China. Man multiplies with the passage of time, wherever war does not check the process. But no other human activity has held men fixed, and made them peaceful and conservative, as rice culture has done.

Industrial development may enable a people to levy on the produce of other lands, and develop a denser population than any agriculture will support, but there is no warrant in history for the expectation that any other means of livelihood will lead to the evolution of a human cultural system as permanent as that associated with the culture of paddy rice has proved to be.

Malaria.—Health takes precedence of wealth as a factor of human progress. The susceptibility of the Hindu to disease and the immunity of the Chinaman have been remarked upon by different writers, and speculation as to the effect of a rice diet is fairly untrammelled by definite information. The relation of beriberi to an improper rice diet and the anti-laxative property of rice have been mentioned before, and with these, established knowledge of the distinctive effects of a rice diet ends.

There is one disease which has long been linked, in the imagination or in fact, with rice culture—malaria. In the Orient there is no general prejudice against rice in this connection, perhaps because the culture of paddy is an indispensable and universal part of the existing order of things, perhaps because of the fact that fevers are most certain and pernicious in unsettled jungles, and less so after the land is cleared and settled—which there means brought into paddy. But in Europe, as the name malaria indicates, the old idea was that intermittent fevers were caused by bad air, more particularly by a sort of effluvium or emanation from wet places. As rice culture involves the accumulation of water and maintenance of humidity, it was naturally viewed with disfavour, and had to establish itself in the face of objection and opposition.

When attention began to be paid to the problems of public health, in comparatively recent years, the first effect was more vigorous opposition to rice culture. An example of it is found in a Spanish Royal decree of 1860, which, with the regulations issued under its authority, provided, among other restrictions, that rice might be

planted only on lands too swampy possibly to be used for any other crop, that it might be planted only where there were no trees or other obstructions to the free circulation of the air, that it might not be planted within 1500 metres of any inhabited place, and that a specific permit must be issued before it might be planted anywhere. It was in the face of these restrictions that Valencia rice became a great industry.

As public hygiene became a science, the relation of rice to the prevalence of fevers was subjected to study, and the statistical evidence showed conclusively that the conversion of swamps to rice fields is eminently favourable to health. Thus, in Novara,[1] sixty years ago, when there was very little rice there, malaria was responsible for about 10 per cent of the sickness; in 1911, when the rice area of the region had reached 69,000 hectares, only 0·6 per cent of the patients were malarial. Figures compiled by Professor Grassi, covering a period of nearly three hundred years, from 1611 to 1900, show a decrease of death-rate in Mortara from 85 per M. to 14 per M., with a remarkable correspondence of the curves representing decrease of death-rate and spread of rice culture. From 1905 to 1909, the average annual death-rate from malaria in all Italy was 14 per 100,000; but during the same years it was only 2·4 per 100,000 in the great rice provinces of Novara and Pavia, where malaria had been very fatal before the rice industry developed.

De Castro [2] lists a series of similar cases in Portugal.

Colmenares [3] has testified likewise from Spanish experience; and many speakers before the Valencia Congress presented statements of the same kind.

Similar experience in California has already been mentioned. Richvale, standing, like Mortara, "like an island in a lake of rice," is remarkable among valley villages for its freedom from malaria. In Europe, the

[1] *Actes du Congrès . . . à Valencia*, p. 111.
[2] De Castro, L., *ibid.* p. 435.
[3] Colmenares, I. G., "Paludisme et culture des rizières," etc., *ibid.* p. 402.

failure of mosquitoes to breed in rice is ascribed to the practice of never letting the water stagnate. But in the most of the test plots of the Health Service in California, it was carefully kept from moving, during months. Yet very few mosquitoes bred in it, and larvae brought in from outside mostly died instead of turning to mosquitoes.[1]

It is not claimed that rice culture and malaria cannot exist together. It is only where malaria is already prevalent that rice improves conditions. And it is not alleged that mosquitoes are exterminated by the substitution of paddies for swamps, though their number may be very much reduced. To eradicate malaria completely, two courses are open: breaking its life cycle in the human body by means of quinine; and breaking it outside the body by exterminating the mosquitoes. Both methods should be used. In Arkansas, where the malaria-bearing mosquitoes breed freely in the paddies, the Health Service's most successful method of killing the larvae was by the use of films of crude oil, over the water. These were applied by scattering on the surface sawdust soaked in oil, after the rice bore several leaves in the air. Arrangements were made for the use of this method, as well as of surface-feeding fish, in California. "However, failure of mosquitoes to breed in rice fields made it impossible to continue the study of remedial measures."

[1] Purdy, W. S., "Biological Investigations of California Rice Fields relative to Mosquito Breeding," *U.S.T.D., Public Health Reports*, 35. (1920), 2556.

INDEX

Printed in Great Britain by R. & R. Clark, Limited, *Edinburgh*.